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PHYSICS 30



Module 4

Current Electricity



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Physics 30

Module 4

Current Electricity

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Physics 30
 Student Module
 Module 4
 Current Electricity
 Alberta Distance Learning Centre
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Welcome to Module 4!

We hope you'll enjoy your study of *Current Electricity*.

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.

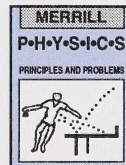


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Frame 4850A

When you see this icon, study the appropriate pages in your textbook.



Good Luck!

Course Overview

This course contains nine modules. The first two modules develop the conservation laws of energy and momentum. The conservation of energy is at the heart of the entire course. Modules 3 through 9 build one upon the other and incorporate the main ideas from the preceding modules.

The module you are working in is highlighted in a darker colour.

PHYSICS 30

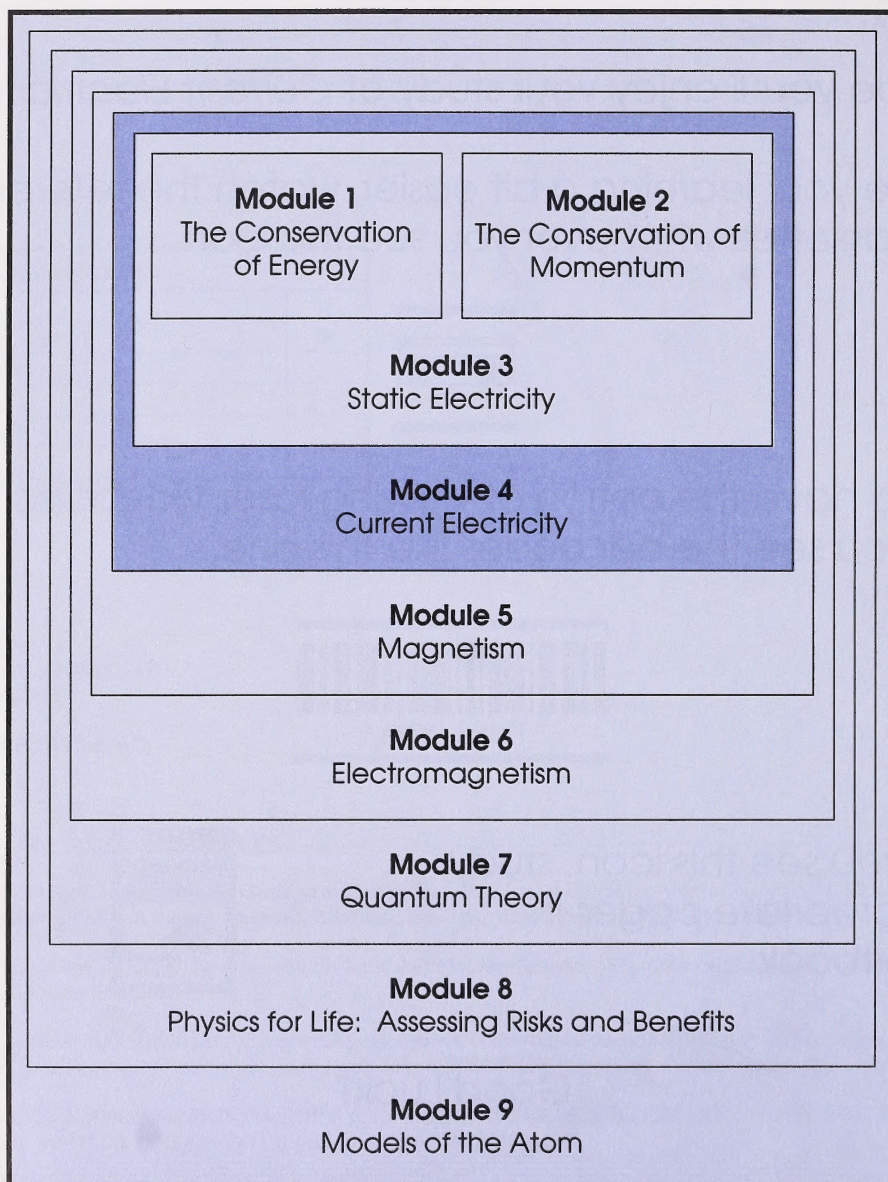


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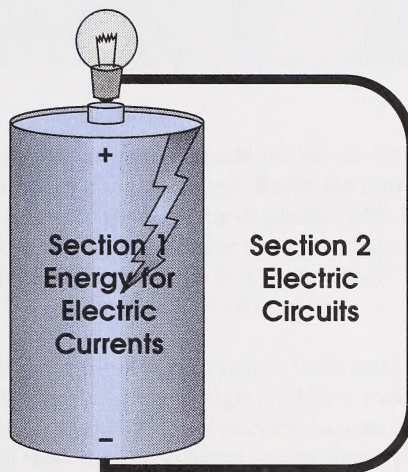
OVERVIEW

It is a week until Christmas and you have decided to test the Christmas tree lights before you put them on the tree. You have noticed that one set is much easier to work with than the other because when one light is burned out, the others still work. The box that this set comes in has **CONVENIENT PARALLEL CIRCUITRY** printed on the side. Unfortunately, you also have another set in which one bad bulb causes all of the other bulbs to fail. Now you are stuck with the task of testing each bulb to find the one that is bad. As you sit testing the bulbs, someone says, "Oh, that set has the bulbs in series."

Why is the parallel arrangement so much more convenient than the series arrangement? Why do some sets of lights warn you not to connect too many sets in a row? Why is it important to replace burnt-out bulbs with bulbs that are the right size?

The answers to these questions involve understanding the basic physics of current electricity and electric circuits. By the end of this module you should be able to provide your own answers to these questions, and you should also have a basic understanding of many other common technologies.

Module 4: Current Electricity



Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete two section assignments. The mark distribution is as follows:

Section 1 Assignment	60 marks
Section 2 Assignment	40 marks
TOTAL	100 marks

1

Energy for Electric Currents



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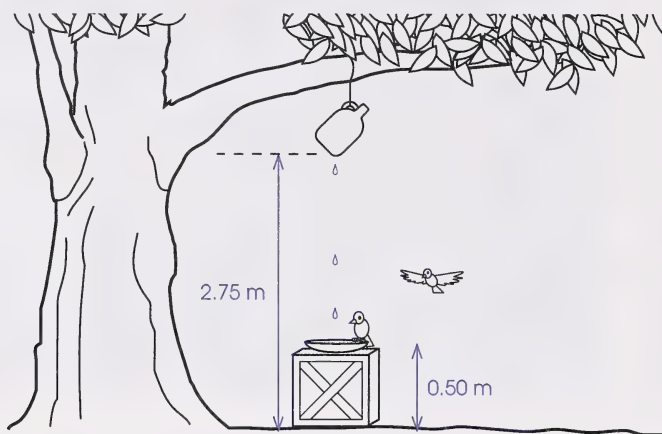
Anyone who has bought a small personal cassette player or a motorized toy has read these familiar words on the front of the package: **Batteries Not Included**. Without batteries, these devices are no more than lumps of plastic with wires inside. Why are batteries so essential? What do they provide for these machines? Are the batteries full of extra electrons? Or do the batteries act like tiny generators? The answers to these questions are based on the law of conservation of energy.

In this section you will learn how these conservation laws can be used to provide a deeper understanding of batteries and the design of simple electric circuits. You will begin by reviewing the energy transitions that occur when an object falls through a gravitational field. You will then use these ideas to develop a parallel set of explanations for a charge falling through an electric field. By the end of the section you will apply these ideas as you investigate a simple electric circuit and explore the properties of basic electric components.

Activity 1: The Physics of Falling Objects

Although it may seem like a strange place to begin the study of electric circuits, it is vital that you first have a thorough understanding of how and why objects fall to Earth.

One application that you can use to study this is a bird bath. A bird bath that allows water to drip from a height and then splash in a puddle will create the kind of sounds that really attract birds. One way to make your own bird bath is to take a 2-L plastic milk jug and hang it from a tree above a large, shallow dish. Add a tiny pin hole to the bottom of the jug. The following diagram shows a possible setup.



1. Why do the drops of water fall from the jug to the dish? Answer in terms of Newton's laws.
2. How does the earth exert a gravitational force on the drops as they fall through the air?
3. If a drop starts from rest, calculate its maximum speed just before it strikes the dish. Consider the accelerated motion of the drop in your answer. Assume that there is very little air resistance.
4. The speed of the drop can also be determined by using the idea of conservation of energy. Use this idea to find the maximum speed of the drop just before it strikes the dish. Begin your answer with a labelled diagram of the setup that identifies the energies involved.

Check your answers by turning to the Appendix, Section 1: Activity 1.

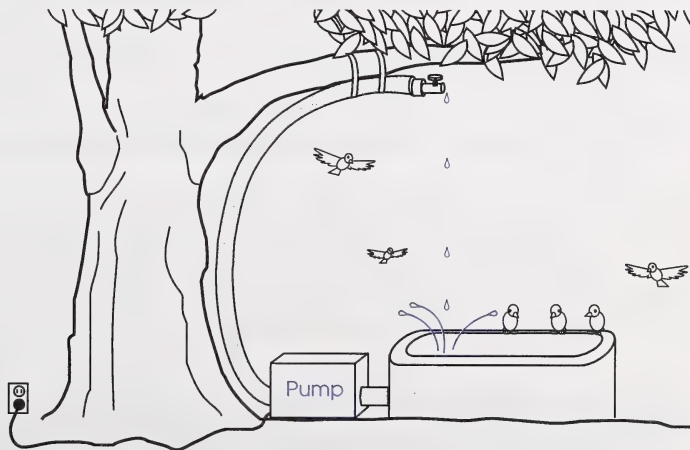
5. What energies were assigned zero values in your answer to the previous question? Explain briefly.
6.
 - a. What equation describes the difference in potential energy between the top and the bottom?
 - b. Where did this potential energy go?
 - c. Is it easier to measure the changes in potential energy or kinetic energy? Explain.

Check your answers by turning to the Appendix, Section 1: Activity 1.

From an energy point of view, it is essential that the jug of water be at a sufficient height above the bird bath that the potential energy of just one drop will be converted into enough kinetic energy to make a splash.

7. A 2.0-L jug of water has a mass of 2.0-kg. Calculate the potential energy of the jug of water relative to the bird bath.

If you plan to make a bird bath, you will need a ladder to set it up. You will have to give the jug potential energy by doing work on the jug and raising it above the bird bath. What's worse is that you will have to do this every three or four hours because the water in the jug will eventually run out. A solution to this problem is to use a water pump and let it do the work for you. The pump will supply potential energy to each kilogram of water that is moved. Of course, the pump will require a source of energy (electricity), but at least you won't be climbing trees three or four times a day!



gravitational potential difference – the ratio of change in potential energy per unit of mass

One way of rating the ability of a water pump is to state its **gravitational potential difference**. The gravitational potential difference is simply the change in gravitational potential energy per mass of water pumped.

$$\text{Gravitational potential difference} = \frac{\text{Change in gravitational potential energy}}{\text{Mass}}$$



$$GPD = \frac{\Delta E_p}{m}$$

8. Suppose a pump had a gravitational potential difference of 22.1 J/kg. Use a calculation to show that a person would have the same rating when carrying a 2.00- kg jug 2.25 m up a ladder.

Check your answers by turning to the Appendix, Section 1: Activity 1.

9. Three pumps all raise water to a height of 2.25 m. Pump A can move 4.00 kg of water, pump B can move 6.00 kg of water, and pump C can move 8.00 kg of water.
- Calculate the gravitational potential difference for each pump.
 - Explain the pattern to your answers for question 9.a.
10. If the mass of water moved doesn't affect the gravitational potential difference, what variables do?
11. Derive a new equation for gravitational potential difference that does not include the mass.
12. a. Verify that the equation that you derived in question 11 works by calculating the gravitational potential difference of the pumps in question 9.
- b. Show by unit analysis that $1 \text{ J/kg} = 1 \text{ m}^2/\text{s}^2$.

Check your answers by turning to the Appendix, Section 1: Activity 1.

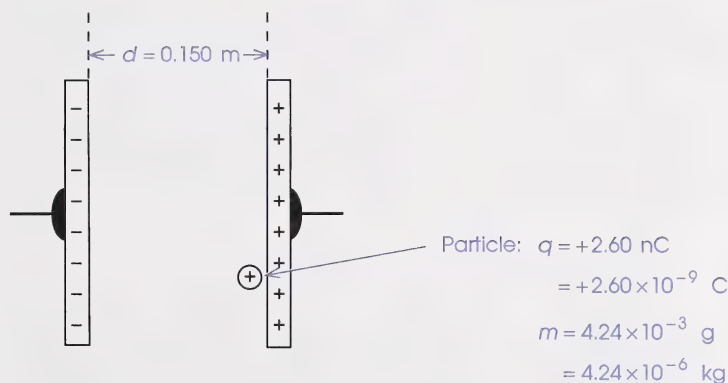
The main thing to remember is that the water pump ensures that there is a difference in height between the two water levels. As long as there is a difference in height, there will be a difference in potential energy and the water will have the energy necessary to flow.

Activity 2: The Physics of Falling Charges

This activity has been designed to be very similar to Activity 1 so that you can clearly see the similarities in concepts. In fact, the first twelve questions in this activity are very similar to the first twelve questions in Activity 1. If you feel that you need additional insight to answer a question in this activity, you should refer to the work that you did in Activity 1.

In this activity you will study the behaviour of charged particles falling between two parallel metal plates that are oppositely charged.

The following diagram shows the arrangement of two plates and the characteristics of the charged particle between them. Use this diagram to answer questions 1 to 3.



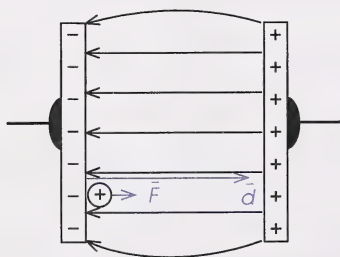
- Given the current position of the particle, why would it fall from the positive plate to the negative plate? Answer in terms of forces.
- Why does the particle experience a force in its present position, even though it is not really touching either plate?
- Redraw the sketch of the parallel plates in your notebook. Be careful to make it the same size or larger than the one shown so that you can add more data and labels.
 - The electric field between the plates has a magnitude of $3.00 \times 10^4 \text{ N/C}$. Add this data to the diagram and sketch the shape of the electric field lines between the plates.

- c. Calculate the magnitude of the force that would act on the particle.
- d. Draw an arrow on the sketch to show the direction of the force vector.
- e. Calculate the magnitude of the acceleration that the particle would experience.
- f. If the particle starts from rest from a position very close to the positive plate, calculate its maximum speed just before striking the negative plate. Answer by considering the accelerated motion of the particle. (Note: Assume that there is no effect from gravity or air resistance.)

Check your answers by turning to the Appendix, Section 1: Activity 2.

Although it took some additional calculations to determine the force and the acceleration, you should have noticed many similarities between the falling charge and the falling water drop. The biggest similarity is that both particles were accelerated from rest by an unbalanced force. The biggest differences were the nature of the forces involved and the directions of each fall.

The energy approach that was applied to the water drop can also be applied to the charged particle. Before attempting this, think about how the charged particle could actually be put so close to the positive plate to begin with.



$$\vec{E} = 3.0 \times 10^4 \text{ N/C}$$

If the particle was imagined to be initially near the negative plate, work would have to be done against the electric field to move it close to the positive plate. This work would increase the potential energy of the charge until it reached a maximum value when it was very near the positive plate.

4. If the charged particle was released from rest at a position very near the positive plate, determine its speed just before hitting the negative plate. Use the law of conservation of energy to solve this problem. Be sure to begin your solution with a carefully labelled diagram of the setup that identifies the energies involved.
5. What energies were assigned zero values in the answer to the previous question? Explain briefly.

6. Why is only the difference in the potential energy of the charged particle measurable?
7. a. Calculate the potential energy of the charged particle as it sits motionless very near the positively charged plate.
- b. How would this value compare to the kinetic energy of the charged particle just before it strikes the negative plate?

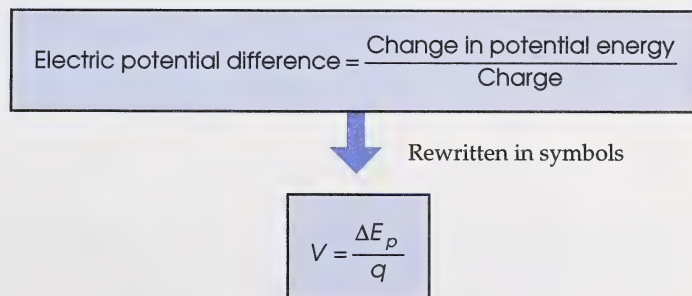
Check your answers by turning to the Appendix, Section 1: Activity 2.

You should remember that the system with the falling water could only maintain itself if there was a pump present to ensure that there was a difference in height between the two water levels. The difference in height ensures that there is a difference in potential energy, and so the water has enough energy to flow.

The situation with these charged plates has similar requirements. For the plates to remain positive and negative, a device like a battery would be required to maintain the difference in potential energy. Without the battery there would be no reason for the charges to stay on the plates and no reason for the point charge to move between them. In this sense, a battery could be thought of as a charge pump.

Just as water pumps can be rated in terms of gravitational potential difference, batteries can be rated in terms of **electric potential difference**, which is sometimes shortened to **potential difference**.

The following flow chart shows how a source of potential difference can be rated.



The units of electric potential difference are energy units divided by charge units. This special ratio is called a volt. It is named after Alessandro Volta, who invented the battery. The flow chart on the next page shows how the units are related.

electric potential difference – the ratio of change in potential energy per unit of charge

$$V = \frac{\Delta E_p}{q}$$

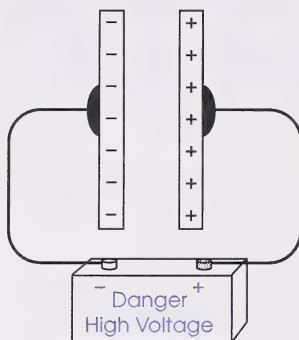
potential difference – an abbreviated term meaning the same thing as electric potential difference

$$1 \text{ volt} = 1 \text{ joule} / 1 \text{ coulomb}$$

Rewritten in symbols

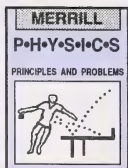
$$1 \text{ V} = 1 \text{ J/C}$$

The first diagram of the two plates can now be redrawn to include the source of electric potential difference.



8. Recall that the particle that you have been working with in this activity has a charge of $+2.60 \times 10^{-9} \text{ C}$ and requires a potential energy increase of $1.17 \times 10^{-5} \text{ J}$ to move from the negative plate to the positive plate. Calculate the potential difference of the battery.
9. Three batteries all have the ability to change the potential energy of charges. Battery A can increase the potential energy of $1.00 \mu\text{C}$ of charge by $6.00 \mu\text{J}$. Battery B can increase the potential energy of 1.00 mC of charge by 6.00 mJ . Battery C can increase the energy of 1.00 C of charge by 6.00 J .
 - a. Calculate the potential difference rating for each battery.
 - b. Explain the pattern to your answers for question 9. a.

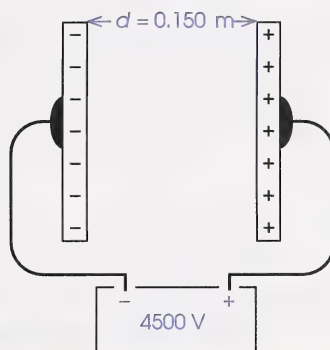
Check your answers by turning to the Appendix, Section 1: Activity 2.



Carefully read the section called The Electric Potential in a Uniform Field on page 433 of your textbook. Note that the textbook uses the symbol E for the magnitude of the electric field. You should use $|\vec{E}|$.

10. If the size of the charge doesn't affect the potential difference rating between two parallel plates, what variables do?
11. Derive a new equation for potential difference between two oppositely charged parallel plates in which the charge has been removed.
12. Verify that the equation that you derived in question 11 works by reconsidering the setup that was introduced at the beginning of this activity.

- a. Calculate the magnitude of the electric field between the plates.
- b. Show by unit analysis that $1 \frac{\text{V}}{\text{m}} = 1 \frac{\text{N}}{\text{C}}$.



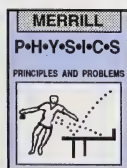
Check your answers by turning to the Appendix, Section 1: Activity 2.

The reason that potential difference is such an important idea to the physics of electric circuits is purely practical. Potential difference is easy to measure, while things like electric field, electric force, and changes in potential energy are much more difficult to measure in an experiment. That is why the equation for the electric field between two parallel plates is usually written as $|\vec{E}| = \frac{V}{d}$, not as $V = |\vec{E}|d$. Potential difference is measured to help determine the electric field, not the other way around.

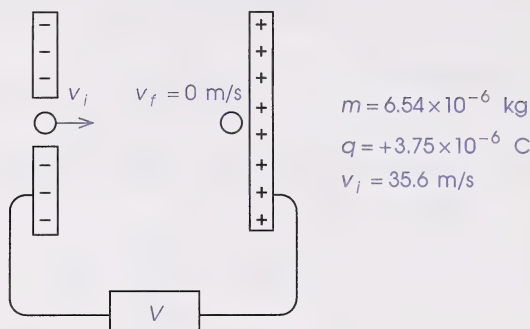
For the remainder of this activity you will practise using what you just learned by solving problems. You will start by completing straightforward questions from the textbook and then you will progress to problems that combine ideas from the whole course. Be sure to use the notation and techniques that you have been using throughout the course.

13. Do Practice Problems 5 to 8 on page 434 of your textbook.

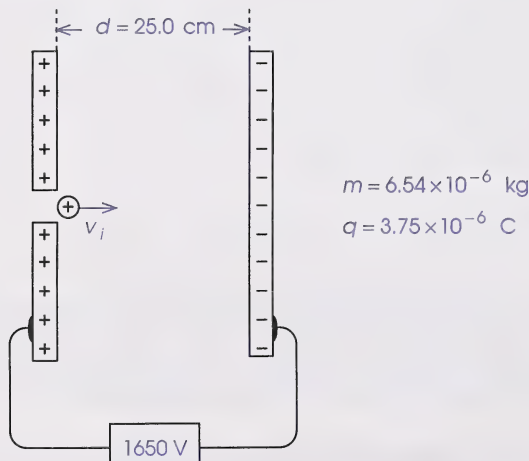
Check your answers by turning to page 680 of your textbook.



14. Two plates are used to stop incoming positively charged particles just before they reach the positive plate.
- a. Copy the diagram into your notebook. In addition to the data supplied, add a sign convention and an indication of where the potential or kinetic energy of the particle may have a zero value.



- b. Find the electric potential difference across the plates using the law of conservation of energy. Ignore gravitational effects as you solve this problem.
15. A positively charged particle with an initial velocity of 35.6 m/s is shot through a hole in a positive plate, as shown in the following diagram.
- a. Copy the diagram into your notebook. In addition to the data supplied, add a sign convention and an indication of where the potential or kinetic energy of the particle may have a zero value.



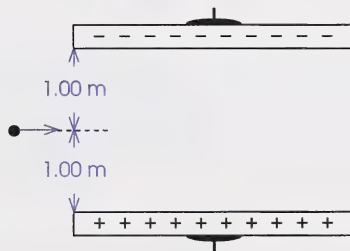
- b. Use the law of conservation of energy to solve for the final velocity of the particle just before hitting the negative plate. Ignore gravitational effects as you solve this problem.

- c. Use the equation $v_f^2 = v_i^2 + 2ad$ to solve for the final velocity of the particle. Ignore gravitational effects as you solve this problem.

Check your answers by turning to the Appendix, Section 1: Activity 2.

Did you notice how the equations for velocity and acceleration from Physics 20 can be combined with the law of conservation of energy and ideas about potential difference from Physics 30? These problems really make the point that fundamental ideas in physics are really very powerful because they can be applied to such a wide variety of phenomena.

16. A particle with a charge of $+2.10 \mu\text{C}$ moves with a horizontal velocity of 4.00 m/s between two parallel plates, as shown in the following diagram. The mass of the particle is $1.05 \times 10^{-2} \text{ g}$. The electric field between the plates has a magnitude of 25.0 N/C . The particle also experiences the effects of the gravitational field.



- Copy the diagram into your notebook. Record all the relevant data and draw an x - y axis for directions.
- Determine the velocity of the particle the instant it strikes a plate. Note that you do not need to find the time to answer this question.
- Determine which plate the particle strikes.

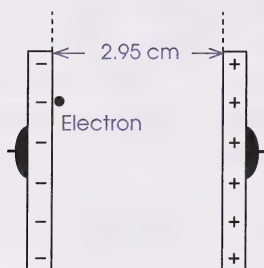
Check your answers by turning to the Appendix, Section 1: Activity 2.

Do gravitational effects always have to be taken into consideration? When the particles are exceptionally small, on the molecular scale or smaller, the gravitational forces are much smaller than the electric forces, so, for a calculation with three significant digits, gravity can be ignored.

When the particles have masses of several kilograms or more, the electrical forces are much smaller than the force of gravity, so electric forces can be ignored for calculations done to three significant digits. Particles that are in between these two extremes will require both forces to be considered. Dust particles, grains of pollen, and pieces of puffed rice in breakfast cereal have masses between 10^{-6} g and 10 g, so these objects will all require both gravitational and electric forces to be considered when doing calculations to three significant digits.

As you complete the next question, be sure to decide whether gravitational forces will need to be considered in your solution.

17. An electron is placed very close to the negative plate, as shown in the following diagram. Although the electron has an initial velocity of zero, it attains a horizontal velocity of 4.13×10^6 m/s the instant before striking the positive plate.

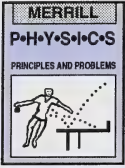


- Copy the diagram into your notebook. Record all the relevant data and draw an x - y axis for directions.
- Calculate the potential difference between the plates.
- Calculate the magnitude of the electric field between the plates.
- Calculate the magnitude of the acceleration of the electron.

Check your answers by turning to the Appendix, Section 1: Activity 2.

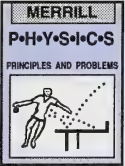
These last problems have really shown the links between many of the most important ideas in Physics 20 and Physics 30.

A more practical application of the energy attained by charges moving through a potential difference concerns the safety of workers transferring flammable liquids to aircraft from large trucks.



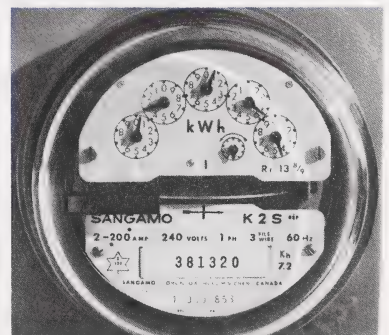
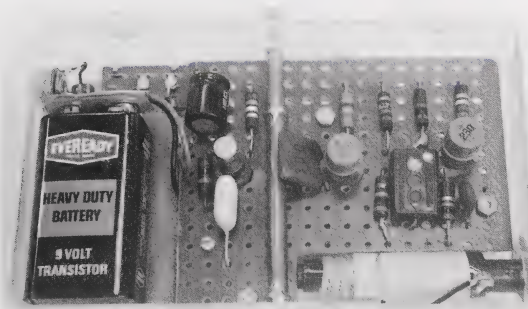
Read pages 438 and 439 in your textbook to find out how these ideas are applied to this situation. When you finish reading, answer the following questions.

18. What condition is necessary for charges to stop flowing between two conductors? Answer in terms of the potential difference between the conductors.
19. How can two conductors have the same potential difference relative to the ground and still have different charges? Refer to Figure 21-10 on page 439 in your textbook as you answer.
20. What is grounding? Refer to charge and potential difference in your answer.
21. Explain why it is important to ground **both** the aircraft and the fuel truck when refuelling.
22. A student who owns a computer needs to take off the top to connect a special chip that will enable the computer to run high-level computer games. The student unplugs the computer and removes the top. The student touches the tips of both index fingers to the large metal legs of the computer table before touching the new chip or the other components of the computer. Why is it important to touch a large metal object before inserting the chip?



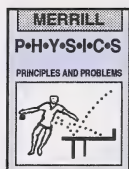
Check your answers by turning to the Appendix, Section 1: Activity 2.

Activity 3: Electric Current



If you were asked to name the most common units used for measuring electric phenomena, what would you say? Although the answers will vary from person to person, most people would likely say volts, amps (or amperes), and watts. What do these units measure and why are they used so frequently?

You already know that the volt measures potential difference. In this activity you will learn what electric current is and how it is measured in amperes. You will also learn how electric power, measured in watts, relates to both current and potential difference. The consideration of potential difference, current, and power is an exceptionally practical set of ideas that will provide you with the background to study electric circuits.



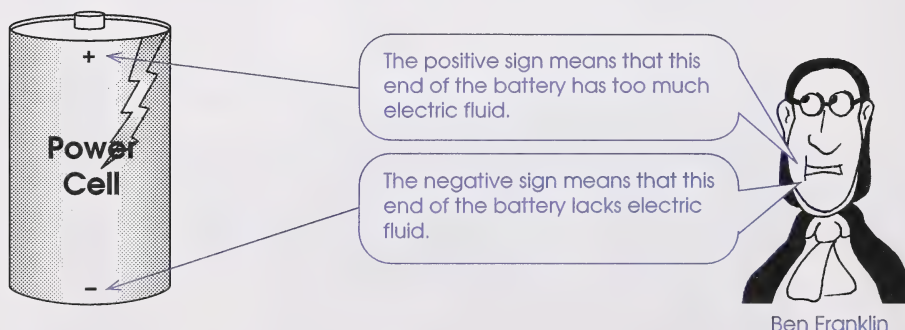
Begin your introduction to electric current by reading from pages 447 to the bottom of page 448 in your textbook. To help identify the main ideas, answer the following questions.

1. Define *electric current*.
2. Do positive charges actually flow through wires? Answer by referring to the location of the positive charge in atoms.

Check your answers by turning to the Appendix, Section 1: Activity 3.

The text mentioned something that should seem strange to you. How can positive charges move as a result of a potential difference when the positive parts of an atom, the protons, are locked tight in the nucleus?

The answer to this question lies in the history of the early work with electricity. Benjamin Franklin was the person who coined the terms *positive* and *negative* because he thought that electricity was an invisible fluid. If Benjamin Franklin had been able to explain the markings on a battery, here's how he'd do it.



If Franklin had been able to look at a flashlight, he'd say that an invisible electric fluid flows from the positive end of the battery, through the light bulb, and then back to the negative end.

This method, or convention, for describing the flow of charges was used internationally for over 100 years before it was discovered that it is actually the electrons that do the moving, not an invisible fluid. Since electrons are negative, they flow from the negative end of the battery, through the light bulb, and to the positive end.

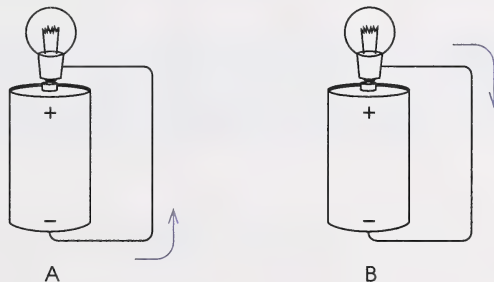
Today, even though it is known that the electrons do the moving, positive charge flow is still used when physicists talk about the direction of an electric current. Since it is also correct to talk about the movement of electrons, it is very important that you are careful and consistent with the wording that you use. The term **conventional current** will be used to describe the movement of imaginary positive charges, while the term **electron flow** will be used to describe the actual movement of electrons.

conventional current – the flow of imaginary positive charges past a point per unit of time
Conventional current flows from the positive terminal of a battery to the negative terminal.

electron flow – the flow of electrons past a point per unit of time
Electron flow goes from the negative terminal of a battery to the positive terminal.

The word *current* will be interpreted to mean *conventional current* in Physics 30. Electron flow should always be specifically indicated.

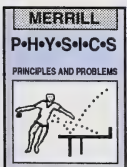
3. The following diagrams show the essential parts of a flashlight: a bulb, a battery, and some wire. The arrow on each diagram shows the direction of the movement of charge.



- a. Which diagram illustrates conventional current and which diagram illustrates electron flow? Explain your answer.
 - b. Which diagram illustrates what physicists would call “current”?
4. Why is conventional current still so widely used?

You can learn more about how batteries pump charges through things like flashlights by reading from the top of page 449 to the bottom of page 450 in your textbook. When you have finished, answer the following questions.

5. What is an electric circuit?



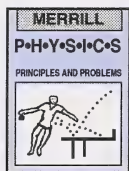
6. Does a battery continually make brand new charges that are consumed and destroyed by the circuit?
7. Define an ampere in terms of other units.
8. Use the definition of the ampere to write an equation for electric current in terms of charge and time.

Check your answers by turning to the Appendix, Section 1: Activity 3.

In the previous question you used units to help develop an equation for electric current. This strategy can also be used to come up with an equation for the electric power consumed by a device. Read the top paragraph on page 451 of your textbook and study the Example Problem to learn the equation for electric power.

9. Do Practice Problems 1 to 4 on page 451 of your textbook.

Check your answers by turning to page 681 of your textbook.



circuit – a closed loop that charges can flow around

Now that you know the definition of electric current, it would be a good idea to deepen your understanding by measuring the electric current yourself as it passes through a simple **circuit**. This is what you will do in an investigation in the next activity. However, before you do that investigation, there are some things that you need to know about electric circuits.

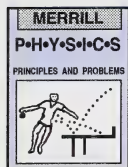
Most electric circuits have the following three main components:

- a source of potential difference: This could be a battery, a generator, or a low-voltage power supply.
- connecting wires: The connecting wires are usually made from a material like copper that passes the current easily with negligible energy loss.
- a load: The load is a device that converts the potential energy possessed by the charges that make up the current into some other form of energy. Thermal energy is always a part of the energy conversion process. For example, if a light bulb was the load, the electric potential energy would be converted into both light energy and thermal energy.

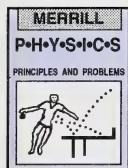
resistor – a device that resists the flow of charge and has a constant resistance

In the investigation the load will be a **resistor**. Resistors are devices that convert electric energy to thermal energy. This occurs because the material that the resistor is made from has atoms that interact and slow down the electrons as they attempt to pass through. In other words, the material resists the flow of charge.

Carefully read the section called Diagramming Circuits on pages 454 and 455 of your textbook. Pay close attention to Figures 22-8 and 22-9 which illustrate the proper connections for ammeters and voltmeters.



10. What does an ammeter measure?
11. What does a voltmeter measure?
12. What is a series connection? Give an example of where a series connection might be used.
13. What is a parallel connection? Give an example of where a parallel connection might be used.
14. A circuit is shown on the bottom of page 456 of your textbook. The small can contains a resistor. Draw the schematic diagram for this circuit.
15. Draw a circuit diagram for a flashlight that includes a 1.5-V battery and a lamp (light bulb) connected in series with an ammeter. Label the positive and negative terminals of the battery. Draw an arrow to indicate the direction in which conventional current would flow.
16. Add to your answer to the previous question to show how a voltmeter would be properly connected to measure the potential difference across the lamp.
17. Consider the circuit described in the previous two questions. If the voltmeter reads 1.55 V and the ammeter reads 25 mA, calculate the power consumed by the light bulb.
18. Referring to the data given in the previous question, how much charge passes through the light bulb in 1.00 s? Express your answer in coulombs.
19. Referring to your answers to the previous two questions, how much energy does 1.00 C of charge possess?
20. Use the answers to the previous two questions to calculate the energy consumed by the bulb in 1.00 s.
21. Draw a circuit diagram for a car's rear-window defroster that includes the 12-V car battery and a heating coil (resistor) connected in series with an ammeter. Label the positive and negative terminals of the battery. Draw an arrow to indicate the direction in which conventional current would flow.



22. Redraw your answer to the previous question to show how a voltmeter would be properly connected to measure the potential difference across the heating coil.
23. If the car battery is supplying 12.1 V to the rear-window defroster that is rated at 200 W, calculate the current that is being drawn by the defroster.

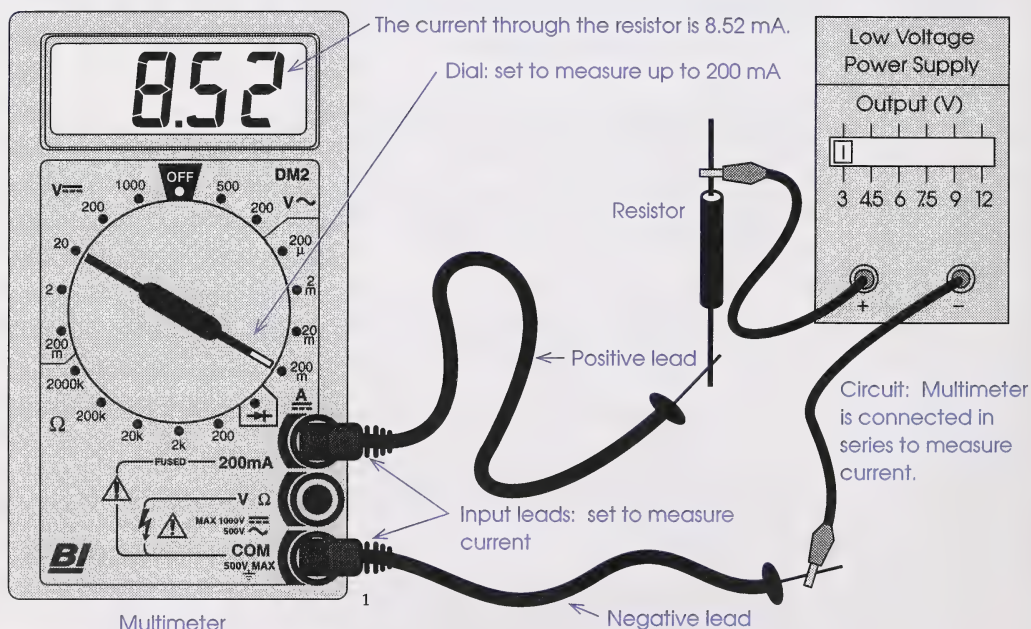
Check your answers by turning to the Appendix, Section 1: Activity 3.

multimeter – a device that can measure a wide range of voltages, currents, and resistances in an electric circuit

Although the examples in the textbook show both a voltmeter and an ammeter being used to take measurements, it is less expensive to use one device that is capable of measuring both quantities. Such a device is called a **multimeter** because it is capable of measuring a number of different quantities. Most multimeters can measure both current and potential difference, so it is likely that this is what you will use for the next investigation.

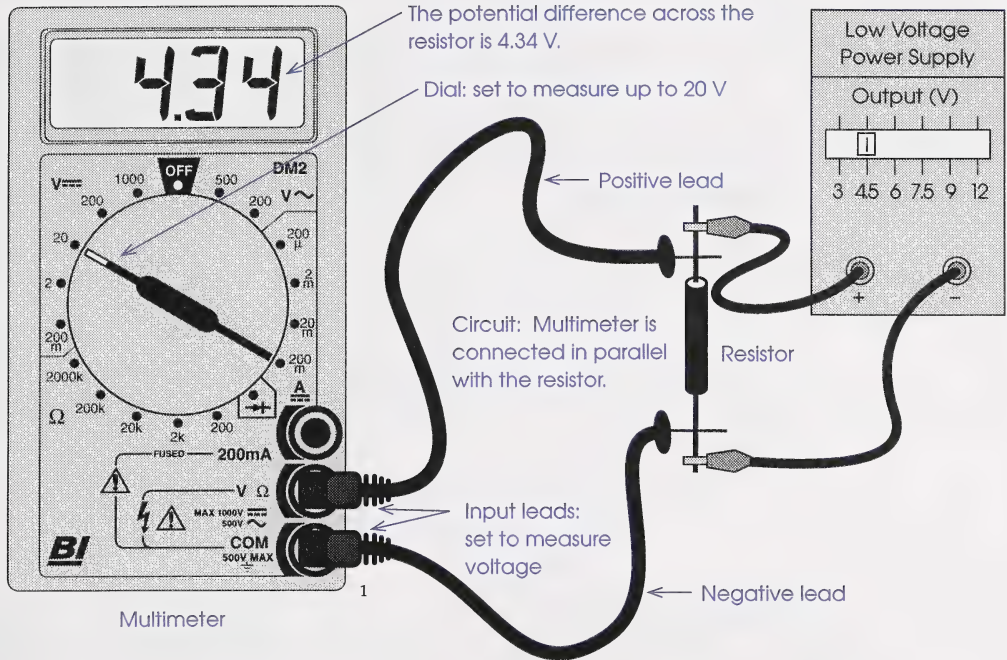
The following diagrams show a typical multimeter being used to measure current and potential difference.

This shows how to correctly measure **current** with a multimeter.



¹ Beckman Industrial Corporation for the diagram of the multimeter face plate, taken from the *Instruction Manual for the Multimeter*.

This shows how to correctly measure **potential difference** with a multimeter.



Note that the negative lead is plugged into the input marked COM, which is an abbreviation for *common*. This refers to the ground (zero potential) that is common to all circuits. The positive lead is plugged into the input for measuring either mA or V. Traditionally, the negative lead is the black one and the positive lead is the red one.

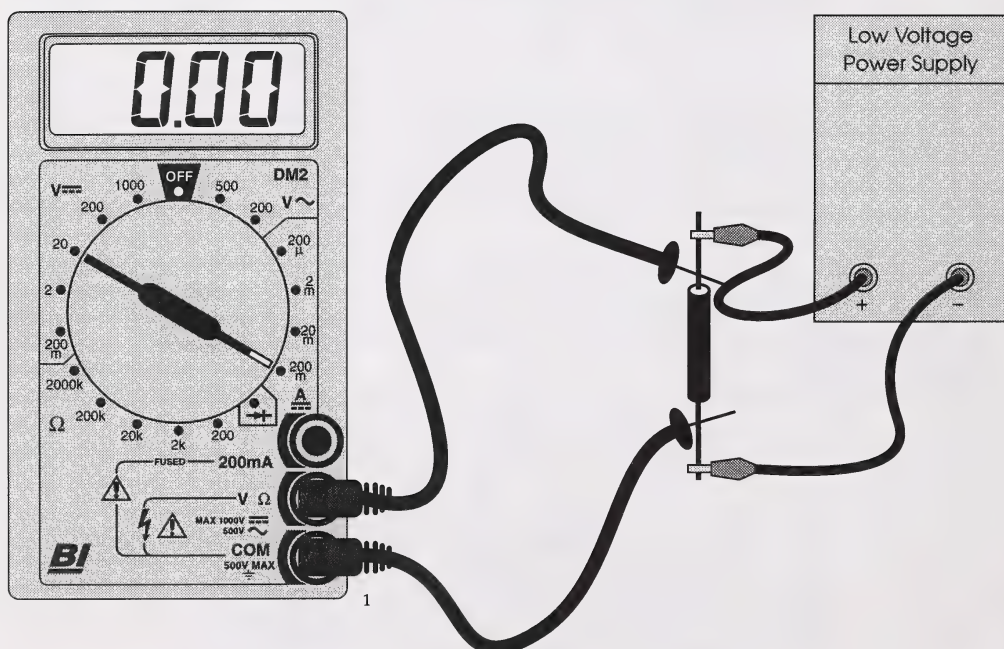
Unfortunately, the cost-effectiveness and convenience of one machine that does everything does have its drawbacks. You have to be very careful that you know what you are measuring and that the following three things are properly adjusted:

- The dial on the meter is set to measure what you want.
- The input leads of the meter are input to measure what you want.
- The circuit has the meter in either series or parallel to measure what you want.

If you forget one of these details, you may blow a fuse in the multimeter. If you are working in a science lab, ask an instructor to check your first attempts using the meter. If you are not working in a science lab, be sure to have a few fuses handy! The following questions are designed to help you be more successful when you start using the multimeter.

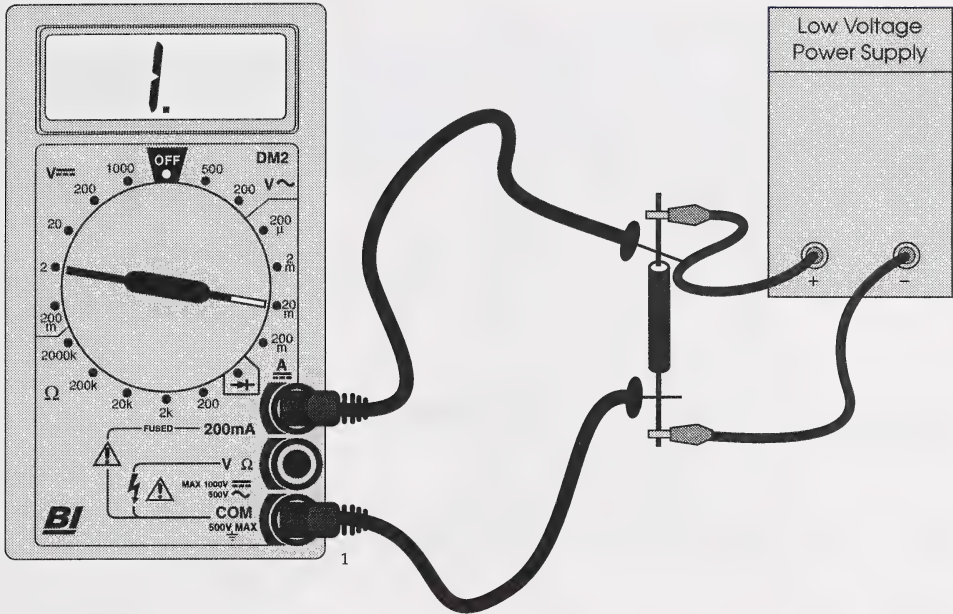
¹ Beckman Industrial Corporation for the diagram of the multimeter face plate, taken from the *Instruction Manual for the Multimeter*.

24. Draw a schematic diagram of the multimeter when it is set to measure current through the resistor. In this case the multimeter is acting like an ammeter.
25. Draw a schematic diagram of the multimeter when it is set to measure potential difference through the resistor. In this case the multimeter is acting like a voltmeter.
26. Refer to the previous diagram. If the sliding knob on the power supply says 4.5 V, should you use 4.5 V or 4.34 V for the value for potential difference across the resistor? Explain.
27. Assume that the same resistor is used in each of the previous two diagrams showing the multimeter. Use the values shown on the meters in these diagrams to calculate the power being consumed by the resistor.
28. The following diagrams show typical errors made while using a multimeter. Write a description of the changes that must be made to each setup to make the desired measurement.
 - a. This shows an **incorrect** attempt to measure current.

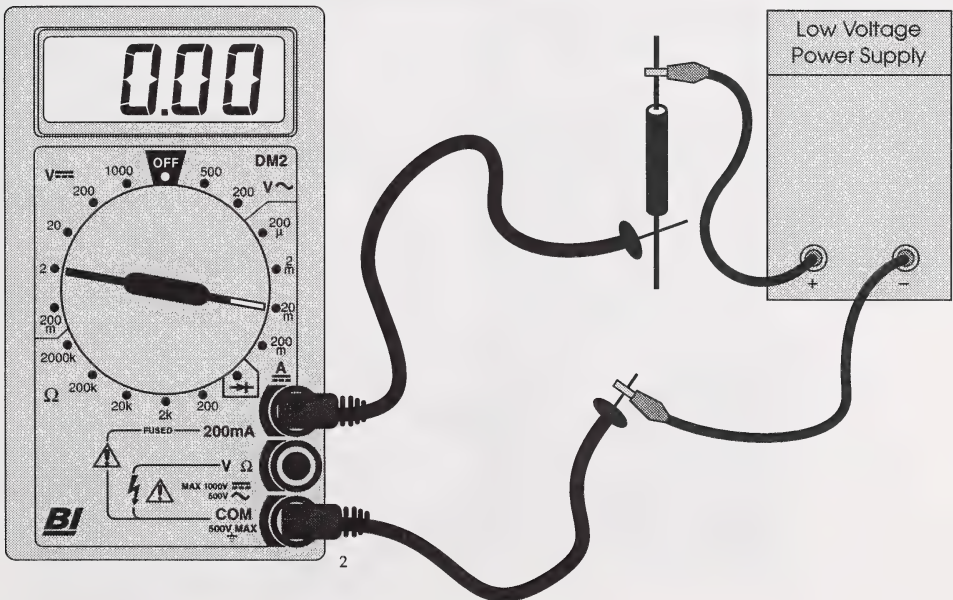


¹ Beckman Industrial Corporation for the diagram of the multimeter face plate, taken from the *Instruction Manual for the Multimeter*.

- b. This shows an **incorrect** attempt to measure current.



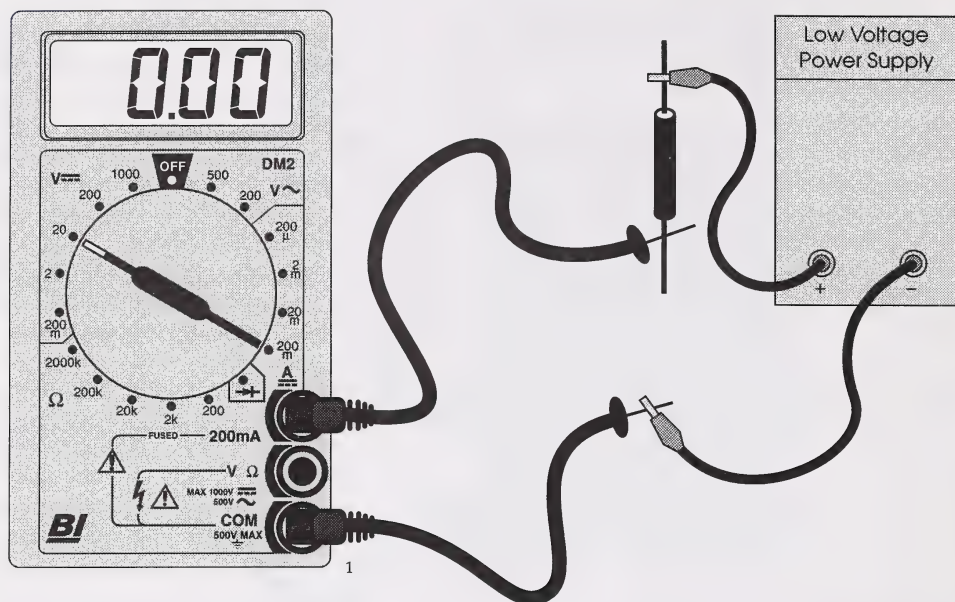
- c. Although this circuit is correctly set up to measure current, the meter won't produce a reading other than zero on any range. What is happening here?



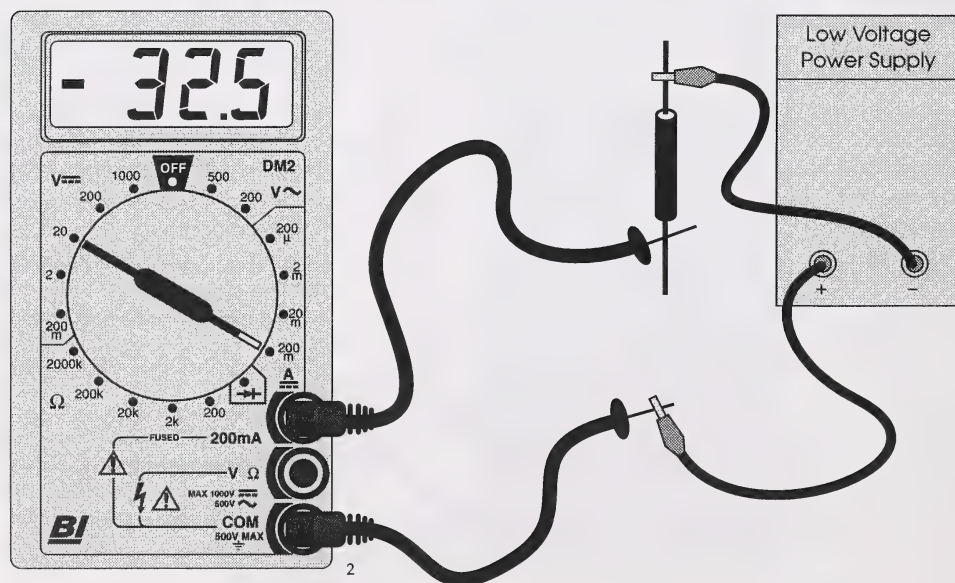
¹ Beckman Industrial Corporation for the diagram of the multimeter face plate, taken from the *Instruction Manual for the Multimeter*.

² See note 1 above.

- d. This shows an **incorrect** attempt to measure potential difference.



- e. This attempt to measure current is producing a negative output. What is happening here?



¹ Beckman Industrial Corporation for the diagram of the multimeter face plate, taken from the *Instruction Manual for the Multimeter*.

² See note 1 above.

29. What are the three things that you should always double check on your multimeter before you attempt to make a measurement?

Check your answers by turning to the Appendix, Section 1: Activity 3.

The things you learned in this activity will be useful throughout the rest of the course. Keep the diagrams of the multimeter handy because they will be a valuable reference tool whenever you set up a circuit.

Activity 4: Ohm's Law

In this activity you will apply what you know about potential difference, current, and the proper use of multimeters to investigate the properties of resistors. By the end of the activity you will be applying these properties to a number of different applications.

Investigation: Measuring Potential Difference and Current for a Resistor

Science Skills

- ☐ A. Initiating
- ☒ B. Collecting
- ☒ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

In this investigation you will determine the relationship between the voltage and the current for different resistors.

Materials

You will need the following materials for this investigation:

- a multimeter (or an ammeter and a voltmeter)
- a DC power supply capable of producing at least six different output voltages
- three resistors that are rated at 0.5 W. The resistors should have the following patterns of stripes:

R_1 – brown, black, red, gold

R_2 – brown, green, red, gold

R_3 – red, black, red, gold

- four test leads with alligator clips at each end
- a power outlet into which you can plug your power supply



Important Safety Precautions

It is very important that you read and apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch metal pipes, electric outlets, light fixtures, etc., that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.
- Only replace the fuse inside the meter with the specified or approved equivalent fuse.
- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.
- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

You will ensure your own safety by applying this information as you complete the investigation.

Procedure and Observations

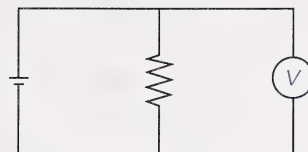
- Read through the entire Procedure and Observations section before you begin. You will be asked to fill in data charts as you do the procedure.
- Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers.

Resistor 1	
V (volts)	I ($\times 10^{-3}$ A)

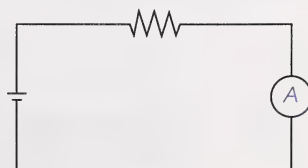
Resistor 2	
V (volts)	I ($\times 10^{-3}$ A)

Resistor 3	
V (volts)	I ($\times 10^{-3}$ A)

- Without turning on the low-voltage power supply, build the circuit as shown in the following photograph and schematic diagram. Be sure to use R_1 .



- Inspect your circuit to check that all connections with the alligator clips are secure and that the multimeter is properly set up and is connected parallel with the resistor.
- If you are in a school science lab, ask the instructor to check your circuit before continuing. If you are working by yourself, check your circuit with the sample diagram that was provided in the previous activity.
- Adjust the knob on the power supply to provide an output of about 3 V and turn on the supply.
- The multimeter should now be reading the potential difference across the resistor. Record this value on the data chart. Don't be surprised if the value indicated by the meter is different than the setting indicated by the knob on the power supply. The value indicated by the power supply knob is only approximate.
- Without changing the setting on the power supply, turn off the power supply and disconnect the multimeter from the circuit. Reset the dial on the meter and the position of the input leads to measure milliamperes. Reconnect the meter as shown in the following photograph and schematic diagram.



- Inspect your circuit to check that all connections with the alligator clips are secure and that the multimeter is properly set up and is connected in series with the resistor.
- If you are in a school science lab, ask the instructor to check your circuit before continuing. If you are working by yourself, check your circuit with the sample diagram that was provided in the previous activity.
- Turn on the power supply once again. The setting on the power supply should not have changed from the previous step.
- The multimeter should now be reading the current through the resistor. Record this value on the data chart.
- Repeat the previous steps at least five more times, each time with a slightly higher potential difference setting on the power supply. **Do not** exceed 20 V. Record your values for potential difference and current on the data chart.
- Repeat the entire procedure for R_2 . Record the data on the appropriate chart.
- Repeat the entire procedure for R_3 . Record the data on the appropriate chart.

Graphing

1. a. Plot the data of potential difference versus current for R_1 . Even though potential difference is actually the manipulated variable, plot it on the y -axis and plot current on the x -axis, as this will make the analysis that follows easier. Use the standard graph paper with 1-cm squares. Be sure to leave sixteen squares on the horizontal axis and twenty squares on the vertical axis.
- b. Draw the best-fit straight line for the points very carefully. Label the line Resistor 1.
- c. Calculate the slope of the best-fit line.
2. Repeat all the parts of question 1 using the data for R_2 . Plot the graph on the same sheet of graph paper that you used for question 1. Label the line Resistor 2.
3. Repeat all the parts of question 1 using the data for R_3 . Plot the graph on the same sheet of graph paper that you used for questions 1 and 2. Label the line Resistor 3.

Check your answers by turning to the Appendix, Section 1: Activity 4.

Graphical Analysis

It is worthwhile to compare the slopes for all three resistors and ask yourself what each slope says about the resistor it represents.

The slope of the potential difference versus current graph for R_1 was probably close to 1000 V/A. This means that it would take about 1000 V to make 1 A flow through R_1 . Close examination of the slope for R_2 reveals that it resists the flow of current more than R_1 because it requires about 1500 V to make 1 A flow. R_3 resists the flow of current most of all because it requires about 2000 V to make 1 A flow.

The ratio of potential difference across a conductor to the current that flows through it is called **resistance**.

resistance –
the ratio of
potential
difference
across a
conductor to
the current
flowing
through the
conductor

$$\text{Resistance} = \frac{\text{Potential difference}}{\text{Current}}$$



$$R = \frac{V}{I}$$

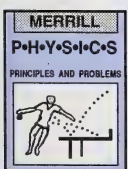
The unit of resistance is the ohm, which is symbolized by the Greek letter omega (Ω).

- State the resistance of all three resistors in ohms.

Conclusions

- State the relationship between the potential difference and the current for a resistor. Support your answer by referring to the graphs.

Check your answers by turning to the Appendix, Section 1: Activity 4.



The relationship between potential difference and current for a conductor is fundamental to understanding the application of electric current in circuits. Read from the bottom of page 451 to the end of the third paragraph on page 452 of your textbook. When you have finished reading, answer the following questions.

- Why is the unit of resistance called an ohm?

In science a law is a general statement that describes how nature behaves. A law must be tested experimentally and be found to apply to a wide variety of circumstances. The law of conservation of energy, the law of conservation of momentum, and Newton’s laws of motion are all good examples.

- Why could it be argued that Ohm’s law is really not a scientific law at all, but rather a description of a property of metal conductors?

Resistors fulfil a very practical role in almost every electric circuit that can be designed. To find out what this role is, read the last two paragraphs on page 452 to the end of the first four paragraphs on page 453 in your textbook. Answer the following questions to help identify the key ideas in the reading.

- What are the two ways to control current in a circuit?
- What is a potentiometer? Give three examples of devices that use a potentiometer.

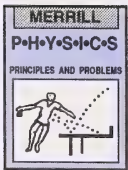
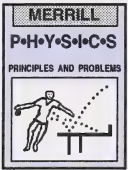
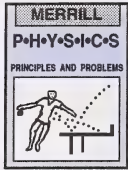
Another application of resistance is its role in explaining why staying dry is so important for your safety when you work with electric devices. Read the last paragraph on page 453 and Biology Connection on page 454 to find out more about resistance and electrical safety. Answer the following questions when you have finished reading.

- Complete two calculations to show the current for using wet hands and dry hands when working with a 120-V source. Express your answers in milliamperes.
- Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Complete the chart by describing the effects on the human body for each of the currents listed.

Effects of Current on the Human Body					
Current	2 mA	10 to 20 mA	20 mA	20 to 100 mA	100 mA to 3A
Effect					

Check your answers by turning to the Appendix, Section 1: Activity 4.

To see how the idea of resistance plays an important role in the design of headlights, motors, lamps, and radios, study the Example Problem on page 453 of the textbook and do the following questions.



12. Do Practice Problems 5 through 10 on page 454 of your textbook.

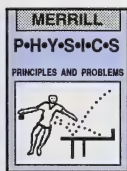
Check your answers by turning to page 681 of your textbook.

Up to this point you have seen how a variety of appliances can be described in terms of the potential difference that they require, the current that they draw, and the resistance that they present to the flow of charges. Why are so many devices run by electricity? What is it about electricity that makes it so widely used?

The answer to these questions concerns energy. The following points summarize some of the reasons why electricity is often the preferred form of energy for so many different things:

- It is efficiently transferred from the initial source (the generating station) to the consumer (you), often over long distances.
- It is easily transformed into other types of energy.
- It is available instantly, making it very convenient.

Although these points in favour of electrical energy are quite straightforward, the technology necessary to make it happen has taken years to develop. You can understand some of the main ideas behind this technology by applying the ideas of voltage, current, resistance, and electric power. Carefully reread page 447, and read from the third paragraph on page 458 to the bottom of page 461 in your textbook. Pay particularly close attention to the Example Problem on page 459. When you have finished this reading, do the following questions.



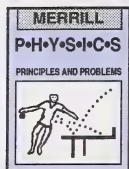
13. Do Practice Problems 14 through 16 on pages 459 and 460 of your textbook.

Check your answers by turning to pages 681 and 682 of your textbook.

**kilowatt
hour** – a unit
for electric
energy used
frequently by
utility
companies
 $1 \text{ kW} \cdot \text{h} =$
 $3.6 \times 10^6 \text{ J}$

Energy is not free – you have to pay for what you use. If you have a portable stereo, you have to buy batteries. If you watch a TV, someone has to pay the electric bill. The electric meter on your home lets the utility company know how much energy your household has been using. However, these meters aren't set up to measure joules or megajoules; they measure **kilowatt hours**.

To find out how kilowatt hours relate to what you already know, read page 462 of your textbook, including the Example Problem at the bottom of the page. When you have finished reading, do the following questions.

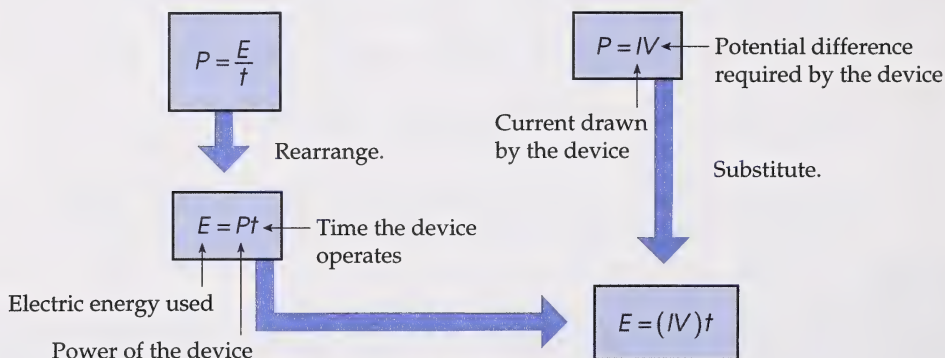


14. Do Practice Problems 18 and 19 on page 463 of your textbook.

Check your answers by turning to page 682 of your textbook.

If you have an outdoor hot tub that is electrically heated, your electric bill will be high, especially in the winter. All the electric energy has to be transferred into thermal energy. In the next investigation you will design an experiment to measure the electric energy that can be transformed into thermal energy for heating water.

When you receive the electric bill, you are charged by the amount of electric energy that you have used. This is shown in the following equations.



It follows from this last equation that the electric energy that is converted into thermal energy should be equal to $(IV)t$. How can this idea be tested? Is there a way to verify this relationship?

Although current, resistance, and time can be directly measured, the increase in thermal energy requires an indirect approach. The easiest method is to use the temperature increase of a known mass of water to calculate the increase in thermal energy. The following equation shows how this can be calculated.

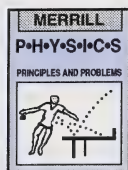
$$Q = mc\Delta T$$

Heat: thermal energy transferred to water (J) →

Change in temperature ($^{\circ}\text{C}$) →

Mass of water (kg) →

Specific heat capacity
(for water, $c = 4.18 \times 10^3 \text{ J/kg} \cdot ^{\circ}\text{C}$) →



If this equation seems unfamiliar to you, read pages 247 and 248 of your textbook to get more information. Check your understanding of this equation by doing the following questions.

15. Do Practice Problems 5 and 6 on page 248 of the textbook.
16. Do Practice Problem 17 on page 460 of the textbook.

Check your answers by turning to the Appendix, Section 1: Activity 4.

Science Skills

- ☒ A. Initiating
- ☐ B. Collecting
- ☐ C. Organizing
- ☐ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Investigation: The Heating Effect of Electric Energy

Purpose

In this investigation you will design an experiment to verify that $E = IVt$.

17. Write up a detailed design of an experiment. Your design should include the following things:
 - a detailed list of the materials needed
 - a procedure that outlines how all the equipment is to be safely set up, how the measurements are to be made, and what safety precautions are needed
 - a sample data chart

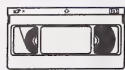
Check your answers by turning to the Appendix, Section 1: Activity 4.

You will continue to apply the concepts of potential difference, energy, power, and current as you explore series and parallel circuits in the next section.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help



You will now review the content of this section by viewing three ten-minute programs of the video series *Electricity*. You should familiarize yourself with the following questions prior to watching the programs. This will help you to focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers.

Important Note

Although the three video-taped programs do a wonderful job of concisely summarizing the main ideas, they do have one drawback. The word *current* is used in each program to talk about electron flow through a conductor.

This is not a habit that you want to adopt. It is very important that you keep conventional current (movement of imaginary positives) and electron flow (movement of electrons) separate and distinct in your mind. As you watch the programs, mentally translate the use of the word *current* on the video to mean "electron flow".

Advance through the video tape until you find the program called *Current Electricity*. The following questions relate to that program.

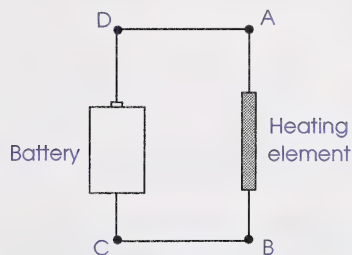
1. Why did Benjamin Franklin state that the moving charges were positive?
2. Why did electricity flow from one sphere to another when a wire was attached?
3. What are the names of the two charged parts in a battery?
4. Explain the path of the electrons and the energy changes when you connect a light bulb to a battery.
5. Draw a simple circuit of a light bulb connected to a battery and label the parts. Draw the schematic diagram for the same circuit.
6. List the differences between a direct current and an alternating current.

Advance through the video tape until you find the program called *Potential Difference*. The following questions relate to that program.

7. List the energy changes in the analogy of an electric circuit (the skier) and in an actual electric circuit.



8. Use the following diagram to answer the questions.



- In which section is there a loss of electric potential energy?
- In which section is there a gain of electric potential energy?
- Which are the sections with the minimum changes in electric potential energy?

Advance through the video tape until you find the program called *Resistance*. The following questions relate to that program.

- What are the differences between a wire used to connect the parts of a circuit and a resistor?
- What happens to the electric potential energy as it goes through a resistor?
- Does the resistance of a resistor change when you connect it to a different circuit?
- When the same amount of current is passed through two different bulbs, why is one brighter than the other?

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

- History of Science

It's easy to take for granted the work and contributions of the scientists who are pioneers in a field. It's interesting to know that sometimes their greatest challenge is dealing with the attitudes and prejudice of other scientists. This was very much the case for Georg Simon Ohm.

Visit a local library and research the life and accomplishments of Ohm. Write a short report that outlines the unkind treatment Ohm received from the scientific community.

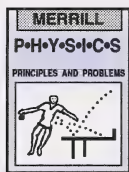
2. Capacitors

If you have ever looked at the back of a stereo amplifier or television set, you have seen a warning printed on the back.

Warning: Electric Shock Hazard

This panel should only be removed by trained service personnel.

Even if the device is unplugged, you can still get a very serious shock because of devices called capacitors that can store large amounts of charge at a high potential difference.



You can find out more about capacitors by reading pages 440 to 442 of your textbook and by answering the following questions.

- Do Practice Problems 13 to 16 on page 442 of your textbook.
- Do Problems 22, 23, and 24 on page 445 of your textbook.

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In this section you have moved from an abstract discussion of energy transitions to the concrete characteristics of electric circuits. Not only should you be able to understand terms like *potential difference*, *current*, and *resistance*, but you should also be able to construct simple circuits and use a multimeter to make measurements.

The skills and ideas developed in this section will become essential for the next section and the modules that follow.

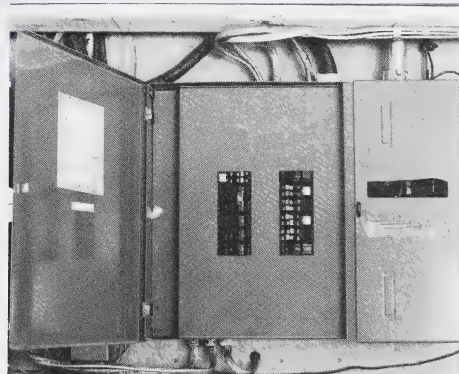
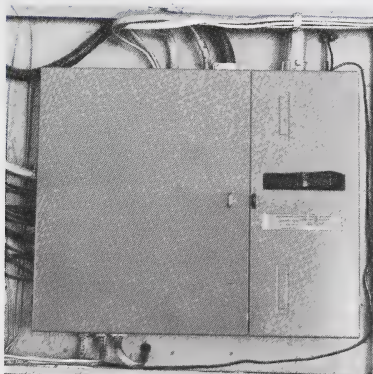
Assignment
Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

2

Electric Circuits



You've been planning the party for weeks and now you are madly rushing to prepare the last of the party snacks and beverages. The toaster oven is melting cheese over biscuits and the microwave oven is heating a sauce. You remember that some people like tea, so you quickly plug in the kettle ... click!

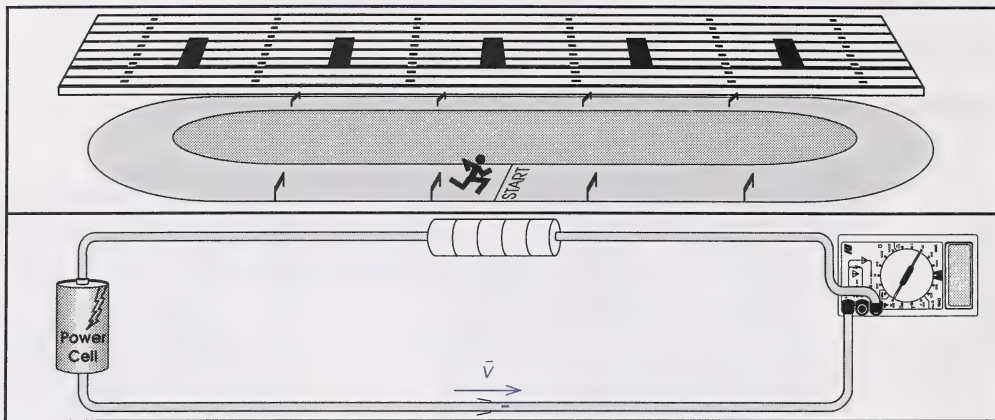
All the appliances stop running. After a few seconds of disbelief, you realize what has happened. In the hurry to have everything ready for your guests, you have forgotten about the limits of the circuit for your kitchen appliances.

The loud click was the circuit breaker being tripped. You turn off all the appliances, go to the electrical panel, and open the door to find the breaker that was tripped.

Has this ever happened to you? In this particular chain of events, the microwave oven, the toaster oven, and the kettle were all connected in parallel on the same circuit. When the kettle was plugged in, the breaker was activated because the current through it exceeded safe limits. The kettle caused more current to flow due to the characteristics of parallel circuits.

In this section you will investigate the properties of series circuits, parallel circuits, and combination circuits. The results of the investigations will be used to derive equations and principles that can be applied to a number of everyday situations.

Activity 1: Series Circuits



In the first drawing the runner runs around the track and jumps hurdles. The runner starts at a spot on the track and eventually returns to the same spot. You would say that the athlete is running in circles. In the second drawing the electron is moving around a circuit.

In a series circuit there is only one path for the electrons to follow. They start at the battery and go along a single path until they return to the battery, where their electric potential energy is increased so that they can repeat the process again and again.

Investigation: The Series Circuit

Science Skills

- ☐ A. Initiating
- ☒ B. Collecting
- ☒ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

It is the purpose of this investigation to determine the properties of a series circuit.

Materials

You will need the following materials for this investigation:

- a DC power supply capable of producing at least six different output voltages (0 V to 20 V)
- a multimeter capable of measuring potential difference (0 V to 20 V), current (0 mA to 20 mA), and resistance (200 Ω to 5000 Ω)

- three resistors rated at 0.5 W power handling, 5% tolerance:

$R_1 = 510 \, \Omega$ (green, brown, brown, gold)

$R_2 = 1000 \, \Omega$ (brown, black, red, gold)

$R_3 = 1500 \, \Omega$ (brown, green, red, gold)

- six test leads with alligator clips at both ends
- three pieces of masking tape, each measuring about 40 mm by 5 mm



Important Safety Precautions

It is very important that you read and apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch metal pipes, electric outlets, light fixtures, etc., that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.
- Only replace the fuse inside the meter with the specified or approved equivalent fuse.
- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.
- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

You will ensure your own safety by applying this information as you complete the investigation.

Background Information

Resistors are usually identified by means of a striped colour code. Although you will always be given the colour code of individual resistors, you may be interested to know how the code works. The first two stripes represent the first two digits in the value of the resistance. The third stripe represents the multiplier (or power of ten) that the first two digits must be multiplied by. The fourth stripe represents the manufactured tolerance. The following chart summarizes the code.

You may find it interesting to check the colour code of the resistors described in the Materials section of this investigation.

Colour	Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Grey	White	Gold	Silver	No color
Number	0	1	2	3	4	5	6	7	8	9			
Multiplier	1	10^1	10^2	10^3	10^4	10^5	10^6	10^7	10^8	10^9	10^{-1}	10^{-2}	
Tolerance											5%	10%	20%

Procedure and Observations

- Read the entire Procedure and Observations section before you begin. You will be asked to write your observations into a data chart as you do the procedure. A completed data chart will be included in the Appendix for your reference.
- Copy the following chart into your notebook. Complete the chart by filling in the missing values with your measurements as you follow the procedure.

$$R_{1+2+3} = \underline{\hspace{2cm}}$$

$$R_{1+2} = \underline{\hspace{2cm}}$$

$$R_1 = \underline{\hspace{2cm}}$$

$$R_2 = \underline{\hspace{2cm}}$$

$$R_3 = \underline{\hspace{2cm}}$$

$$V_1 = \underline{\hspace{2cm}}$$

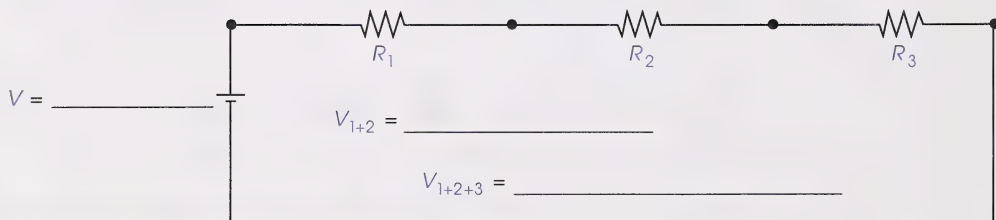
$$V_2 = \underline{\hspace{2cm}}$$

$$V_3 = \underline{\hspace{2cm}}$$

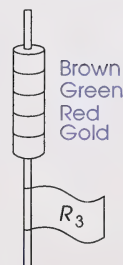
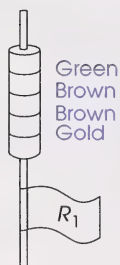
$$I_1 = \underline{\hspace{2cm}}$$

$$I_2 = \underline{\hspace{2cm}}$$

$$I_3 = \underline{\hspace{2cm}}$$



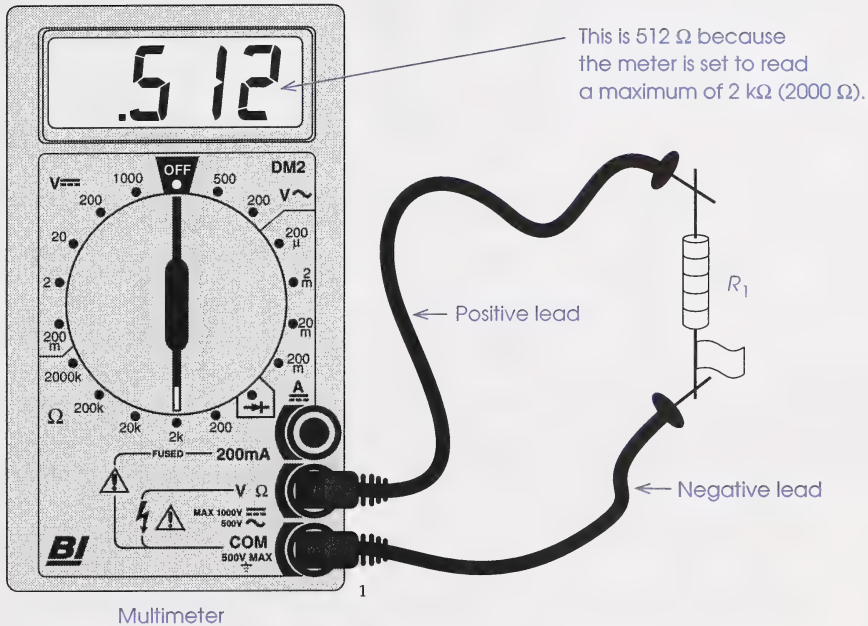
- Wrap the tape around the wire lead of each resistor, as shown in the following sketch.



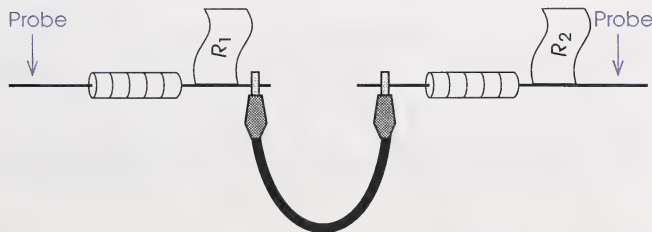
- Label the resistors R_1 , R_2 , and R_3 . Be careful to match the number to the correct sequence of stripes on each resistor.

Measuring Resistance Values

- Set the dial on the multimeter to measure resistance in ohms and determine the resistance of each resistor by touching the leads across each resistor. The following diagram shows the proper technique for a typical multimeter.

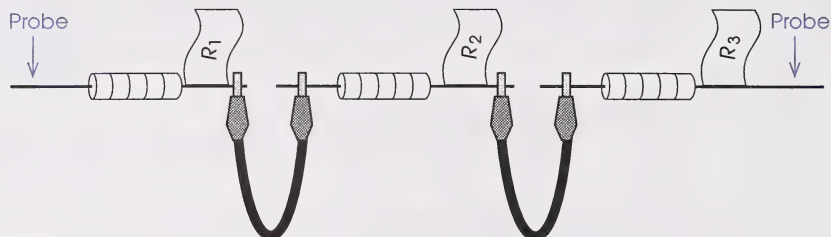


- Record the resistance of the three resistors on the data chart.
- Use a connecting wire to attach R_1 to R_2 . Measure the resistance of R_1 and R_2 in series. Note that one probe of the multimeter is to be connected to the open end of R_1 , while the other probe is connected to the open end of R_2 .



¹ Beckman Industrial Corporation for the diagram of the multimeter face plate, taken from the *Instruction Manual for the Multimeter*.

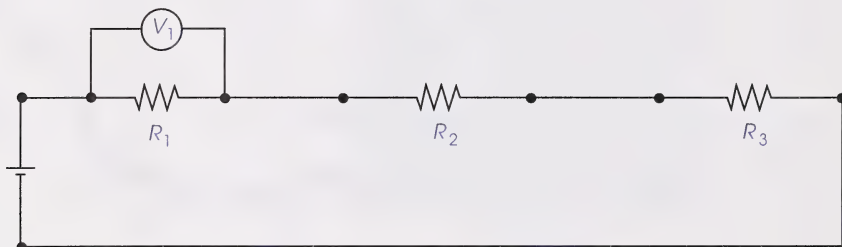
- Record the resistance of R_1 and R_2 in series on the data chart.
- Use a connecting wire to attach R_3 in series with R_1 and R_2 . Measure the resistance of these three resistors in series. You may have to change to the 20-k Ω scale to get a resistance value for this setup.



- Record the value of R_1 , R_2 , and R_3 in series on the data chart.

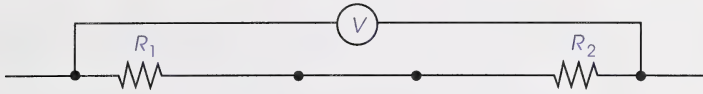
Measuring Potential Difference

- Without turning on the power supply, construct the following circuit.

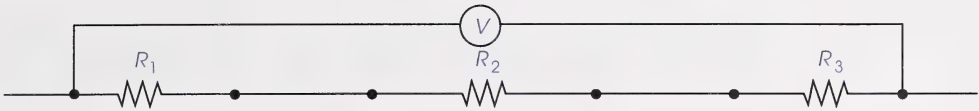


- Adjust the power supply to a constant output of between 12 V and 20 V. Once you have this set, do not change it again throughout the experiment.
- Inspect the circuit to check that all connections with the alligator clips are secure and that the multimeter is properly set up and is connected parallel with the resistor.
- If you are in a school science lab, ask the instructor to check your circuit before continuing. If you are working by yourself, check your circuit with the sample diagram that was provided in the previous section.
- Turn on the power supply. Measure the potential difference across each resistor. Record your values on the data chart.

- Measure the potential difference across R_1 and R_2 . The following diagram of part of the circuit shows how. Record this value on the data chart.



- Measure the potential difference across R_1 , R_2 , and R_3 . The following diagram of part of the circuit shows how to do this. Record this value on the data chart.



- Disconnect the power supply from the circuit as soon as your measurements are complete.

Measuring Current

- Adjust the leads and the dial on the multimeter to measure current. To measure current, you have to have the multimeter in series with the resistors. To measure the current through R_1 , have the meter in series between R_1 and R_2 . The following diagram of part of the circuit shows how to do this. Record this value on the data chart.



- Measure the current through R_2 and R_3 , as shown in the following diagrams of part of the circuit. Record these values on the data chart.

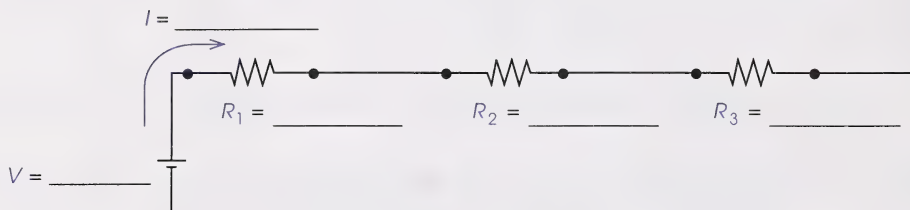


- Save the resistors, complete with the tape labels, so that they can be used in the next investigation.

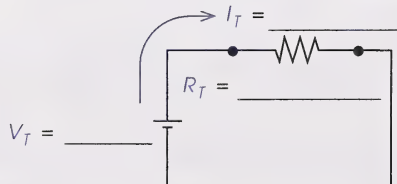
Analysis

1. The potential difference across all three resistors, V_{1+2+3} , relates to the voltage output of the power supply. What do these measurements reveal the output of the power supply to be?
2. How do the individual voltage drops across each resistor relate to the total voltage output of the power supply?
3. Explain your answer to the previous question in terms of energy.
4. How do the individual values for the current through each resistor compare to each other? How do the individual current values through each resistor compare to the current output by the power supply?
5. Explain your answer to the previous question.
6. How do the individual values for resistance compare to the total resistance across all three resistors?
7. Copy the following flow chart into your notebook. Complete the flow chart by labelling the values of each of the quantities indicated. Use the data chart that you completed to find the values.

Original Circuit



If all the resistors were replaced with an **equivalent resistance**, R_T , and the current did not change, the circuit would look like this.



I_T is the total current through the whole circuit and V_T is the total potential difference across the whole circuit.

equivalent resistance – the value of a single resistor that could replace a group of resistors in a circuit and not change the current

8. Calculate a theoretical value of R_T using V_T and I_T . How does the actual value of R_T compare?

Check your answers by turning to the Appendix, Section 2: Activity 1.

Conclusions

Looking at your answers to the Analysis questions, you should be able to make the following generalizations about the properties of a series circuit.

$$R_T = R_1 + R_2 + R_3 + \dots$$

$$V_T = V_1 + V_2 + V_3 + \dots$$

$$I_T = I_1 = I_2 = I_3 = \dots$$

$$V_T = I_T R_T$$

The things that you discovered about series circuits have a wide application to many common devices. Now that you know the properties of series circuits, you can see how your textbook explains these same ideas.

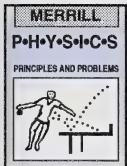
Read pages 470 to 471 in your textbook. Check your understanding of the ideas by answering the following questions.

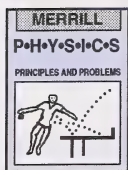
9. What is an equivalent resistance?

Check your answers by turning to the Appendix, Section 2: Activity 1.

10. Do Practice Problems 1 to 4 on pages 471 and 472 in your textbook.

Check your answers by turning to page 682 of your textbook.



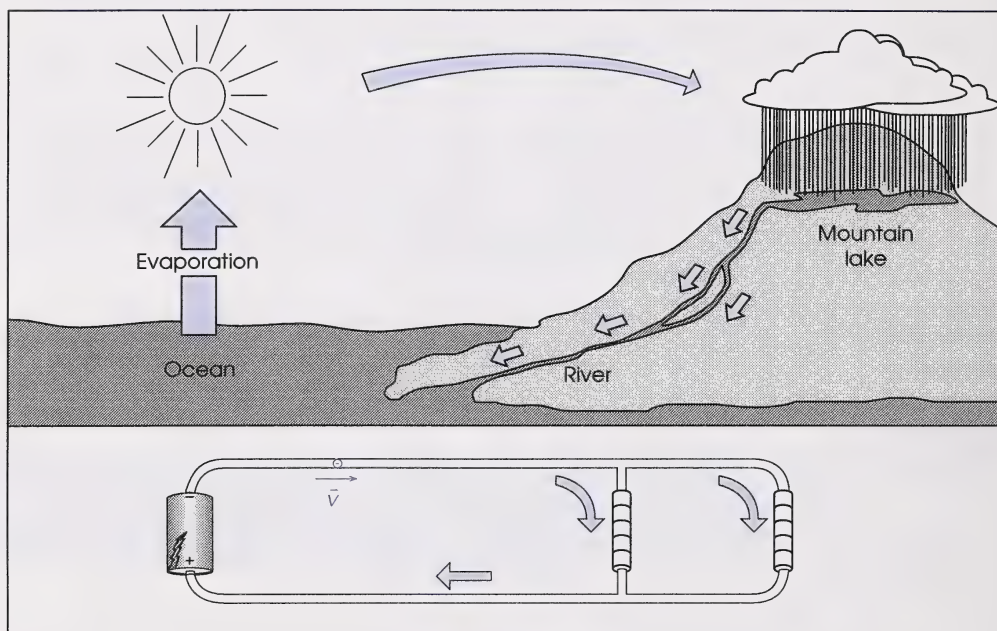


One frequently used application of a series circuit is a voltage divider. To find out how a voltage divider works, read pages 472 to 474 in your textbook. Pay close attention to the Example Problems provided. When you have finished reading, do the following questions.

11. Do Practice Problems 5 through 8 on pages 474 and 475 of your textbook.

Check your answers by turning to page 682 of your textbook.

Activity 2: Parallel Circuits



In the first illustration water flows down from the mountains to the sea or ocean. The river breaks into different paths, but later on it joins up again. In the second illustration the electrons also branch and then rejoin to create a single path.

In this activity you will see circuits which follow the same pattern illustrated in these diagrams. Electrons flow in the wire, but at times they arrive at a junction and split up for a while and then rejoin at another place.

Investigation: The Parallel Circuit

Science Skills

- ☐ A. Initiating
- ☒ B. Collecting
- ☒ C. Organizing
- ☒ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

It is the purpose of this investigation to determine the properties of a parallel circuit.

Materials

You will need the following materials for this investigation:

- a DC power supply capable of producing at least six different output voltages (0 V to 20 V)
- a multimeter capable of measuring potential difference (0 V to 20 V), current (0 mA to 50 mA), and resistance (200 Ω to 5000 Ω)
- three resistors rated at 0.5 W power handling, 5% tolerance:

$R_1 = 510 \ \Omega$ (green, brown, brown, gold)

$R_2 = 1000 \ \Omega$ (brown, black, red, gold)

$R_3 = 1500 \ \Omega$ (brown, green, red, gold)

- six test leads with alligator clips at both ends
- three pieces of masking tape, each measuring about 40 mm by 5 mm

Important Safety Precautions

It is very important that you read and apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch metal pipes, electric outlets, light fixtures, etc., that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.
- Only replace the fuse inside the meter with the specified or approved equivalent fuse.
- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.

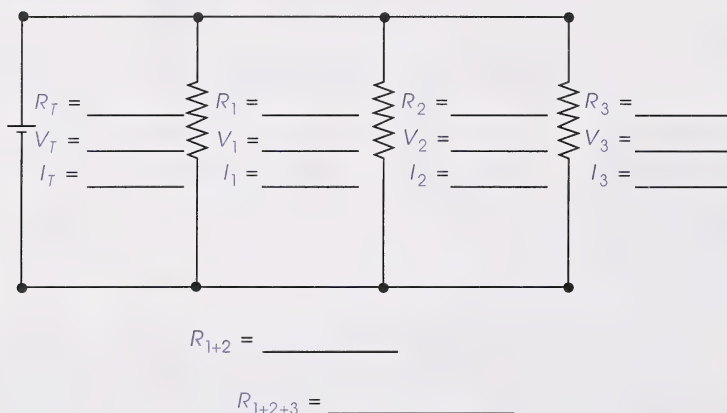
Caution

- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

You will ensure your own safety by applying this information as you complete the investigation.

Procedure and Observations

- Read the entire Procedure and Observations section before you begin. You will be asked to write your observations into a data chart as you do the procedure. A completed data chart will be included in the Appendix for your reference.
- Copy the following chart into your notebook. Complete the chart by filling in your observations as you do the procedure.

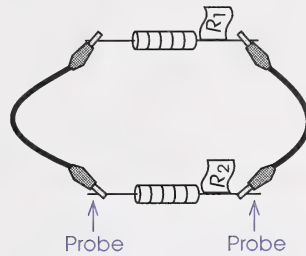


- If you saved the three resistors from the previous investigation, you may use them again for this investigation. If you did not save the resistors from the last investigation, you will have to label some with masking tape as you did for the other investigation. Refer to the instructions in the previous investigation.

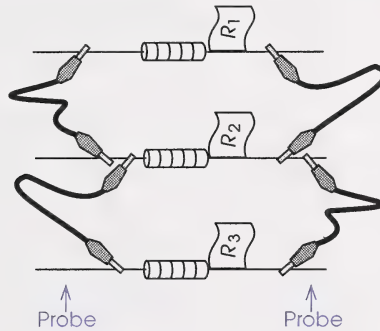
Measuring Resistance

- Set the dial and the input leads of the multimeter to measure resistance.
- If you are using the same resistors as in the previous investigation, you can use the resistance values that you obtained in the previous investigation. If you are using different resistors, you will need to measure the resistance of each one. Refer to the previous investigation for specific instructions.
- Record the values of the individual resistors on the data chart.

- Connect R_1 and R_2 in parallel. Measure the resistance of the combination, as shown in the following diagram. Record this value in the data chart.

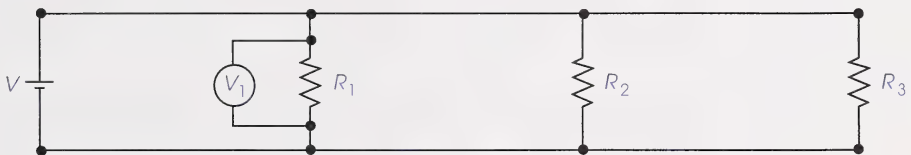


- Connect R_1 , R_2 , and R_3 in parallel. Measure the resistance of this combination, as shown in the following diagram. Record this value in the data chart.



Measuring Potential Difference

- Without turning on the power supply, construct the following circuit.

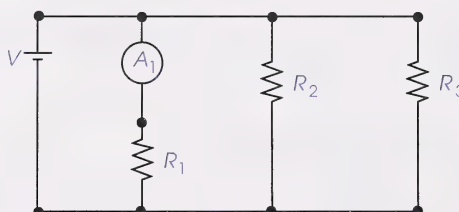


- Adjust the power supply to provide a constant output of between 5 V and 10 V. Once you have this output set, do not change it again throughout the experiment.
- Inspect the circuit to check that all connections with the alligator clips are secure and that the multimeter is properly set up and is connected in parallel with the resistor.

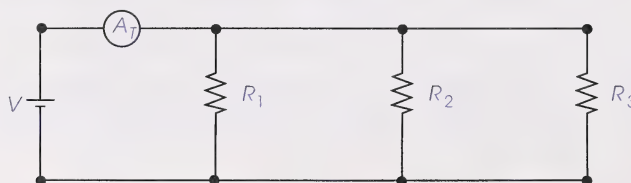
- If you are in a school science lab, ask the instructor to check your circuit before continuing. If you are working by yourself, check your circuit with the sample diagrams that were provided in Section 1.
- Turn on the power supply. Measure the potential difference across R_1 . Record this value on the data chart.
- Repeat the previous step by touching the probes to the ends of resistors R_2 and R_3 . Record these values of potential difference on the data chart.
- Measure the potential difference, V_T , provided by the power supply while it is connected to the resistors. Record this value on the data chart.

Measuring Current

- Adjust the leads and the dial on the multimeter to measure current. To measure current, you have to have the multimeter in series with the resistors.
- Connect the multimeter in series to the branch of the circuit containing R_1 , as shown in the following diagram. Record the current travelling through R_1 on the data chart.

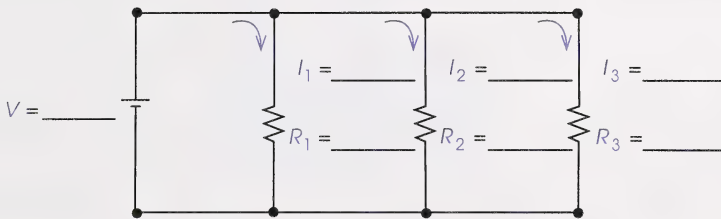


- Repeat the previous two steps for each of the other resistors. Record the current values on the data chart.
- Connect the multimeter in series with the power supply, as shown in the following diagram. Record the value of the total current, I_T , provided to the circuit by the power supply on the data chart.

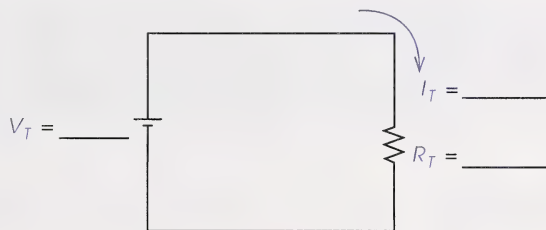


Analysis

1. How do the individual voltage drops across each resistor relate to the total voltage output of the power supply?
2. Explain your answer to the previous question in terms of energy.
3. How do the individual values for the current through each resistor compare to the total current provided by the power supply?
4. Explain your answer to the previous question.
5. How do the individual values for resistance compare to the total resistance of all three resistors connected in parallel?
6. Copy the following diagram into your notebook. Complete the diagram by labelling the values of each of the quantities indicated. Use the data chart that you completed to find the values.



If all the resistors were replaced with an equivalent single resistor, R_T , such that the total current did not change, the circuit would look like this.



7. Calculate a theoretical value for R_T using V_T and I_T . How does the actual value of R_T compare?

Although it may seem strange at first, it does make sense that the total resistance of the three resistors in parallel is less than the individual values. Each resistor that is added in parallel provides another path for current, allowing more current to flow and lowering the overall resistance.

The following derivation shows that an equation can be developed for the equivalent resistance of a parallel circuit.

$$I_T = I_1 + I_2 + I_3$$



Apply Ohm's law to each current value.

$$\frac{V_T}{R_T} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$



Since $V_T = V_1 = V_2 = V_3$, these values can be replaced with V .

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$



Divide all terms by V .

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

8. Using the measured values of R_1 , R_2 , and R_3 , calculate the total resistance, R_T , using the previous equation. How does this value for R_T compare to the measured value of R_T ?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Conclusions

Looking at your answers to the Analysis questions, you should be able to make the following generalizations about the properties of parallel circuits.

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

$$V_T = V_1 = V_2 = V_3$$

$$I_T = I_1 + I_2 + I_3 + \dots$$

$$V_T = I_T R_T$$

You can confirm that you understand the main ideas of the previous investigation by reading pages 475 to 477 in your textbook. Be sure to read through the Example Problem carefully. When you have finished reading, do the following questions.

9. Do Practice Problems 9 to 12 on pages 477 to 478 of your textbook.

Check your answers by turning to page 682 of your textbook.

One of the places where parallel circuits are used is in household wiring. Many of the safety devices used to protect you and your home are based on principles that you have studied in this module. Read pages 480 to 482 in your textbook to find out how these devices work. When you have finished reading, answer the following questions.

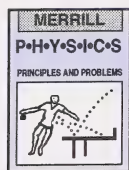
10. Why is it important to place a limit on the size of the current that is flowing through household wiring?
11. Explain how a fuse limits current to a maximum value.
12. Explain how a circuit breaker limits current to a maximum value.
13. How does a ground-fault interrupter protect someone who is using an appliance in a wet location?
14. What is a short circuit?

Check your answers by turning to the Appendix, Section 2: Activity 2.

In the next activity you will apply the main ideas from this module to circuits that contain both parallel and series elements.

Activity 3: Combination Circuits

Many electric appliances and electronic devices contain circuits that have resistors both in series and in parallel. The analysis of these circuits can be accomplished by replacing the combinations of series and parallel components with equivalent resistances. In general it is always best to start with the components that are furthest away from the source of potential difference and work your way back to the source.



The textbook mentions some other helpful suggestions on page 482 and provides an example on page 483. Read these pages and study the Example Problem that is provided. When you have finished reading, do the following questions.

1. Do Practice Problems 13, 14, and 15 on page 484 of your textbook.

Check your answers by turning to page 683 of your textbook.

Sometimes the method of replacing groups of resistors with an equivalent resistance does not work because the circuit is too complex. In these cases a new approach is required.

You have probably begun to notice that the most difficult problems that you have tackled so far in Physics 30 have usually been solved by starting with Newton's laws or a conservation law, since these ideas state basic truths about how nature behaves. In addition, these laws can be applied to a wide range of circumstances. This is what makes these laws so important in physics.

This case is no exception. G. R. Kirchhoff invented two rules that are very helpful in the analysis of complex combination circuits. These rules are based on the law of conservation of charge and the law of conservation of energy.

Kirchhoff's junction rule –

The sum of the currents entering a junction must equal the sum of the currents leaving the junction.

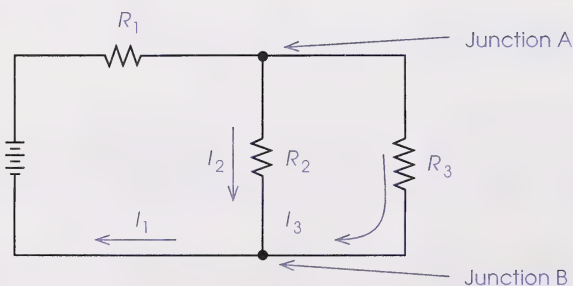
$$\sum I_{in} = \sum I_{out}$$

junction – a point in a circuit where three or more conductors meet

Kirchhoff's Junction Rule

A **junction** is a place at which three or more conductors are joined. Kirchhoff's junction rule simply says that the sum of the currents entering a junction must equal the sum of the currents leaving the junction.

As an example, reconsider the circuit that you read about in the Example Problem on pages 482 and 483 of your textbook.



Kirchhoff's junction rule could be applied to junction B as follows.

$$\sum I_{in} = \sum I_{out}$$

$$I_2 + I_3 = I_1$$

2. Turn to the Example Problem on page 483 of your textbook and look up the values of I_1 , I_2 , and I_3 . Do these values verify that the currents follow Kirchhoff's junction rule?
3. How would Kirchhoff's junction rule be applied to junction A?
4. How is Kirchhoff's junction rule related to the law of conservation of charge?

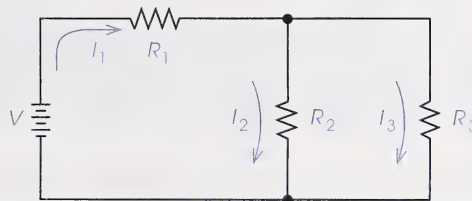
Check your answers by turning to the Appendix, Section 2: Activity 3.

Kirchhoff's Loop Rule

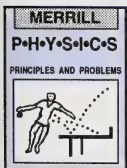
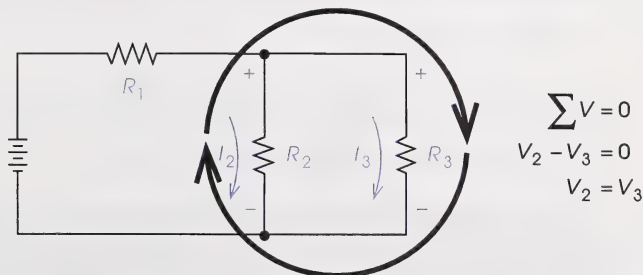
Kirchhoff's loop rule –
The algebraic sum of the potential differences around any closed loop of a circuit must be zero.

$$\sum V = 0$$

This rule states that the algebraic sum of the potential differences around any closed loop of a circuit must be zero. To see how this can be applied, think about the circuit that you read about in the Example Problem on page 483 of your textbook.



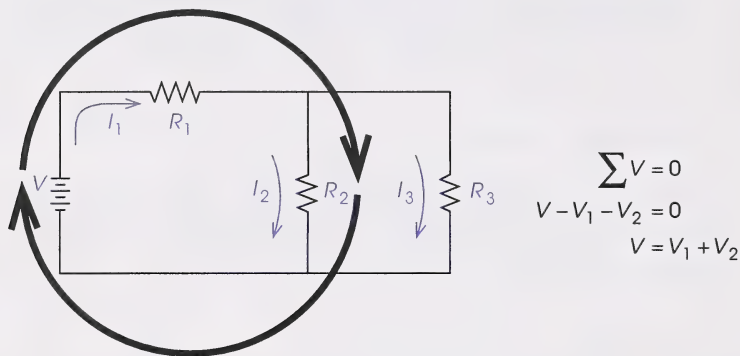
Kirchhoff's loop rule could be applied to the loop containing R_2 and R_3 as shown.



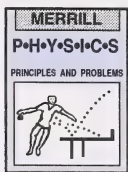
If the charges travel around the loop in the direction shown, the potential difference increases as they go from the negative side to the positive side of R_2 . This is why V_2 is a positive value in the second step of the equation shown with the previous diagram. Since the charges would experience an increase in their potential energy going in this direction through R_2 , their potential difference would also be increased.

However, if the charges keep traveling in the same direction, they would eventually encounter R_3 , where they would lose potential energy. Since there is a loss in potential energy, there must also be a loss in potential difference. The negative sign in the second step of the equation indicates this energy loss.

It doesn't matter which way you think about charge flow around the loop, just as long as you are consistent and think about gains and losses of potential energy very carefully. As an example, consider the loop of the following circuit containing a battery and two resistors, R_1 and R_2 . Here's how Kirchhoff's loop rule would be applied here.

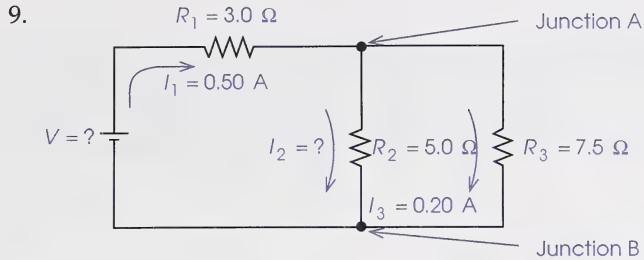


5. Why is V given a positive value in the second step of the equation, while V_1 and V_2 are given negative values?
6. Use the values for the problem printed on page 483 of your textbook to verify that $V = V_1 + V_2$. (Note: The textbook uses the symbol V_p for both V_2 and V_3 .)
7. Apply Kirchhoff's loop rule to the large outside loop containing the battery, R_1 , and R_3 in the previous diagram.
8. Verify the equation that you developed in the previous question by checking it against the values printed on page 482 and 483 of your textbook. (Note: The textbook uses the symbol V_p for both V_2 and V_3 .)



Check your answers by turning to the Appendix, Section 2: Activity 3.

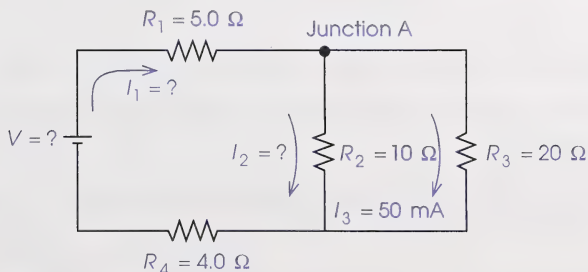
Now that you have seen how each of Kirchhoff's rules work, it is time to use them together to solve some problems.



- Apply Kirchhoff's junction rule to solve for I_2 .
- There is another way to calculate I_2 . Apply Kirchhoff's loop rule to the loop containing R_2 and R_3 to solve for I_2 . You will also have to use Ohm's law.
- Apply Kirchhoff's loop rule to the outside loop of the circuit (containing R_1 and R_3) to solve for the potential difference of the battery. You will also have to use Ohm's law.
- Check your answer to question 9. c. by applying Kirchhoff's loop rule to the loop containing R_1 and R_2 to solve for the potential difference of the battery. You will also have to use Ohm's law for this solution.

Check your answers by turning to the Appendix, Section 2: Activity 3.

10. Use the following schematic diagram to answer each part of this question.



- Apply Kirchhoff's rules and Ohm's law to find the value of I_2 .

- b. Apply Kirchhoff's rules to find the value of I_1 .
- c. Apply Kirchhoff's rules to find the value of V .

Check your answers by turning to the Appendix, Section 2: Activity 3.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

Imagine that you have the following materials:

- a battery that can provide a total voltage of V_T
- two different resistors, R_1 and R_2
- connecting wires

Use this list of materials and their appropriate symbols to answer the following questions.

1.
 - a. Draw a large schematic diagram of the two resistors connected to the battery in series. Leave room on your diagram for labels for current and potential difference. Title the entire diagram Properties of Series Circuits.
 - b. Label the potential difference supplied by the battery as V_T . Label the potential difference across each resistor as V_1 and V_2 respectively.
 - c. Write an equation to describe how these potential differences are related.
 - d. Show that one of Kirchhoff's rules supports the answer that you developed in question 1. c.
 - e. Label the current that is supplied by the battery and the current that flows through each resistor as I_T , I_1 , and I_2 respectively.
 - f. Write an equation to show how these current values are related.

- g. Write an equation to show how the resistance values, R_1 and R_2 , relate to the equivalent resistance, R_T , for this circuit.
2. a. Draw a large schematic diagram of the two resistors connected to the battery in parallel. Leave room on your diagram for labels for current and potential difference. Title the entire diagram Properties of Parallel Circuits.
 - b. Label the potential difference supplied by the battery as V_T . Label the potential difference across each resistor as V_1 and V_2 respectively.
 - c. Write an equation to show how these potential difference values are related.
 - d. Label the current that is supplied by the battery and the current that flows through each resistor as I_T , I_1 , and I_2 respectively.
 - e. Write an equation to show how these current values are related.
 - f. Show which one of Kirchhoff's rules supports the answer that you developed in question 2. e.
 - g. Write an equation to show how the resistance values, R_1 and R_2 , relate to the equivalent resistance, R_T , for this circuit.

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

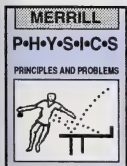
Do **one** of the following questions.

1. Robots and Ohm's Law

Read the Physics and Technology section on page 486 of your textbook and answer the question at the end of the section.

2. Imagine that you have six $1.0\text{-k}\Omega$ light bulbs and want to light up your deck. How should you connect them (series or parallel) so that it won't be expensive to leave them on at night? Assume that you want to leave them on for 8.0 h and the cost is $7.0\text{¢}/\text{kW}\cdot\text{h}$.

- a. Draw the schematic diagram for both scenarios.



- b. Calculate the cost for both scenarios. Assume that you run the lights from a 120-V source.
- c. Which is the least expensive setup?
- d. Which setup would give you the most light?

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you investigated the properties of series and parallel circuits and applied these properties to a number of different situations. The section ended by studying combination circuits that have both series and parallel components.

The important thing to remember here is that these applications and the technologies that use them are all based on basic principles in physics. As you saw with Kirchhoff's junction rule and loop rule, the laws of conservation of energy and charge are the foundation of all of these ideas.

Assignment
Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

MODULE SUMMARY

You should now have answers to some of the very basic questions which were asked at the beginning of this module. Why are Christmas lights much more convenient if they have the bulbs connected in parallel instead of in series? Why does plugging in one more appliance to an already full circuit trip the circuit breaker? The answers to these questions should give you insight into a number of different situations that you may encounter.

Appendix



Glossary

**Suggested
Answers**

Glossary

ampere: the unit of electric current $\left(1 \text{ A} = \frac{1 \text{ C}}{\text{s}}\right)$

circuit: a closed loop that charges can flow around

combination circuit: a circuit containing both series and parallel elements

conventional current: the flow of imaginary positive charges past a point per unit of time

Conventional current flows from the positive terminal of a battery to the negative terminal.

current: an abbreviated term meaning the same thing as electric current

electric current: the ratio of the amount of charges that pass a point per unit of time $\left(I = \frac{q}{t}\right)$

electric potential difference: the ratio of change in potential energy per unit of charge $\left(V = \frac{\Delta E_p}{q}\right)$

electric power: the ratio of the electric energy used per unit of time

The electric power can be calculated in terms of potential difference, current, and resistance.

$$P = IV \quad P = I^2 R \quad P = \frac{V^2}{R}$$

electron flow: the flow of electrons past a point per unit of time

Electron flow goes from the negative terminal of a battery to the positive terminal.

equivalent resistance: the value of a single resistor that could replace a group of resistors in a circuit and not change the current

grounding: the act of touching a charged object to the earth to eliminate excess charge

gravitational potential difference: the ratio of change in potential energy per unit of mass

junction: a point in a circuit where three or more conductors meet

kilowatt hour: a unit for electric energy used frequently by utility companies

$$1 \text{ kW} \cdot \text{h} = 3.6 \times 10^6 \text{ J}$$

Kirchhoff's junction rule: The sum of the currents entering a junction must equal the sum of the currents leaving the junction. $\left(\sum I_{in} = \sum I_{out}\right)$

Kirchhoff's loop rule: The algebraic sum of the potential differences around any closed loop of a circuit must be zero $\left(\sum V = 0\right)$.

multimeter: a device that can measure a wide range of voltages, currents, and resistances in an electric circuit

ohm: the unit of resistance $\left(1 \Omega = \frac{1 \text{ V}}{\text{A}}\right)$

Ohm's law: The ratio of the potential difference across a conductor to the current that flows across the conductor is constant $\left(R = \frac{V}{I}\right)$.

parallel connection: More than one path is available for electron flow through devices connected in parallel.

potential difference: an abbreviated term meaning the same thing as electric potential difference

resistance: the ratio of potential difference across a conductor to the current flowing through the conductor

resistor: a device that resists the flow of charge and has a constant resistance

series connection: Only one path is available for electron flow through devices connected in series.

volt: the unit of electric potential difference
 $1 \text{ V} = \text{J/C}$

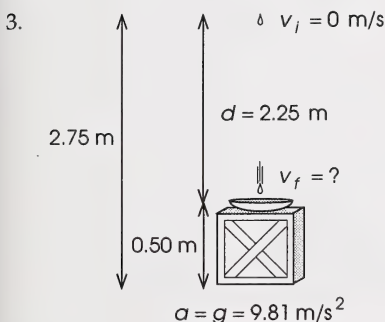
voltage: a common term meaning the same thing as electric potential difference

Suggested Answers

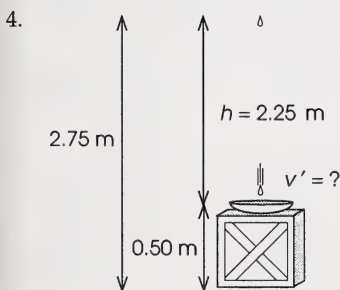
Section 1: Activity 1

1. The water drops fall from the jug because an unbalanced force acts on each drop. According to Newton's second law, $\vec{F}_{net} = m\vec{a}$. In this case the downward force of gravity accelerates the drop towards the dish, as given by $\vec{F}_g = m\vec{g}$.

2. The earth is able to exert a gravitational force on the drop through its gravitational field. The gravitational field, $\vec{g}$, allows each drop to experience the force of gravity even though it is not touching the earth.



$$\begin{aligned}
 v_f^2 &= v_i^2 + 2ad \\
 v_f^2 &= 2ad \\
 v_f &= \sqrt{2ad} \\
 &= \sqrt{2(9.81 \text{ m/s}^2)(2.25 \text{ m})} \\
 &= \sqrt{44.145 \text{ m}^2/\text{s}^2} \\
 &= 6.64 \text{ m/s}
 \end{aligned}$$



Before falling:

$$\begin{aligned}
 E_k &= \frac{1}{2}mv^2 = 0 \\
 E_p &= mgh
 \end{aligned}$$

After falling:

$$\begin{aligned}
 E_k &= \frac{1}{2}mv'^2 \\
 E_p &= 0
 \end{aligned}$$

$$\sum E_{before} = \sum E_{after}$$

$$E_k + E_p = E_k' + E_p'$$

$$E_p = E_k'$$

$$mgh = \frac{1}{2}mv'^2$$

$$v'^2 = 2gh$$

$$v' = \sqrt{2gh}$$

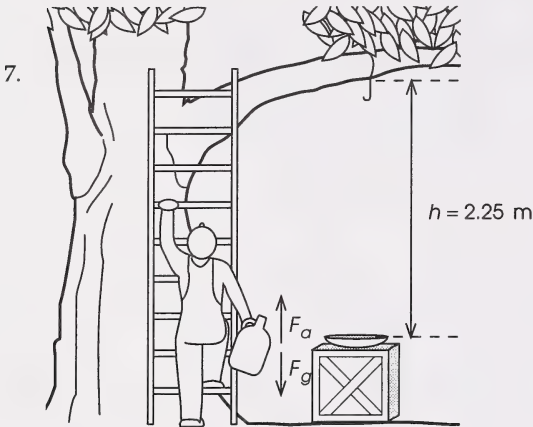
$$= \sqrt{2(9.81 \text{ m/s}^2)(2.25 \text{ m})}$$

$$= \sqrt{44.145 \text{ m}^2/\text{s}^2}$$

$$= 6.64 \text{ m/s}$$

5. The kinetic energy at the top of the drop's fall was assigned a zero value because the drop was initially at rest. The potential energy at the dish was assigned a zero value for convenience in solving this problem. Potential energy can be set to zero at any location.

6. a. The difference in potential energy can be described by $mgh - 0 = mgh$.
- b. The potential energy was converted to kinetic energy as the water drops fell to the dish.
- c. Changes in potential energy are much easier to measure than changes in kinetic energy because the kinetic energy requires that the exact speed of the object be known for a particular time. Actually, the speed is an instantaneous value which is impossible to measure; it can only be approximated by finding the average speed over a very short time interval.



$$\begin{aligned}
 E_p &= mgh \\
 &= (2.0 \text{ kg})(9.81 \text{ m/s}^2)(2.25 \text{ m}) \\
 &= 44.145 \text{ J} \\
 &= 44 \text{ J}
 \end{aligned}$$

8. $m = 2.00 \text{ kg}$
 $h = 2.25 \text{ m}$
 $g = 9.81 \text{ m/s}^2$
 $GPD = ?$

$$\begin{aligned}
 GPD &= \frac{\Delta E_p}{m} \\
 &= \frac{mgh}{m} \\
 &= \frac{(2.00 \text{ kg})(9.81 \text{ m/s}^2)(2.25 \text{ m})}{2.00 \text{ kg}} \\
 &= 22.07 \text{ J} \\
 &= 22.1 \text{ J}
 \end{aligned}$$

9. a. Pump A

$h = 2.25 \text{ m}$
 $g = 9.81 \text{ m/s}^2$
 $m = 4.00 \text{ kg}$
 $GPD = ?$

$$\begin{aligned}
 GPD &= \frac{\Delta E_p}{m} \\
 &= \frac{mgh}{m} \\
 &= \frac{(4.00 \text{ kg})(9.81 \text{ m/s}^2)(2.25 \text{ m})}{4.00 \text{ kg}} \\
 &= 22.1 \text{ J/kg}
 \end{aligned}$$

Pump B

$$h = 2.25 \text{ m}$$

$$g = 9.81 \text{ m/s}^2$$

$$m = 6.00 \text{ kg}$$

$$GPD = ?$$

$$\begin{aligned} GPD &= \frac{\Delta E_p}{m} \\ &= \frac{mgh}{m} \\ &= \frac{(6.00 \text{ kg})(9.81 \text{ m/s}^2)(2.25 \text{ m})}{6.00 \text{ kg}} \\ &= 22.1 \text{ J/kg} \end{aligned}$$

Pump C

$$h = 2.25 \text{ m}$$

$$g = 9.81 \text{ m/s}^2$$

$$m = 8.00 \text{ kg}$$

$$GPD = ?$$

$$\begin{aligned} GPD &= \frac{\Delta E_p}{m} \\ &= \frac{mgh}{m} \\ &= \frac{(8.00 \text{ kg})(9.81 \text{ m/s}^2)(2.25 \text{ m})}{8.00 \text{ kg}} \\ &= 22.1 \text{ J/kg} \end{aligned}$$

- b. The answers for gravitational potential energy are the same for each pump because the mass of water is multiplied by gh and then divided by the mass. The mass values cancel in each case.

10. Gravitational potential difference is determined by the acceleration due to gravity and the difference between the heights of the water levels.

$$\begin{aligned} 11. \quad GPD &= \frac{\Delta E}{m} \\ &= \frac{mgh}{m} \end{aligned}$$

$$GPD = gh$$

12. a. $GPD = gh$

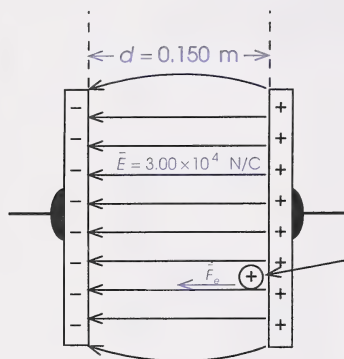
$$\begin{aligned} &= (9.81 \text{ m/s}^2)(2.25 \text{ m}) \\ &= 22.1 \text{ m}^2/\text{s}^2 \end{aligned}$$

- b. $1 \text{ J/kg} = 1 \text{ N} \cdot \text{m/kg}$

$$\begin{aligned} &= \frac{1 \left(\frac{\text{kg} \cdot \text{m}}{\text{s}^2} \right) \text{m}}{\text{kg}} \\ &= \frac{\text{m}^2}{\text{s}^2} \end{aligned}$$

Section 1: Activity 2

1. The positive particle is both attracted to the negative plate and repelled from the positive plate, creating an unbalanced electric force on the particle. According to Newton's second law, this unbalanced force should cause the particle to accelerate towards the negative plate, as given by $\vec{F} = m\vec{a}$.
2. The plates are able to exert an electric force on the particle through the electric field that is present between the plates. The electric field, $\vec{E}$, allows the particle to experience the electric force even though it is not touching either plate.
3. a.



The particle: $q = +2.60 \text{ nC}$
 $= +2.60 \times 10^{-9} \text{ C}$
 $m = 4.24 \times 10^{-3} \text{ g}$
 $= 4.24 \times 10^{-6} \text{ kg}$

b. This question is answered on the previous sketch.

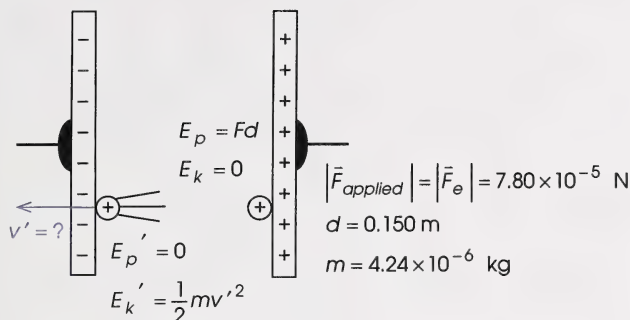
$$\begin{aligned} \vec{F}_e &= \vec{E}q \\ |\vec{F}_e| &= |\vec{E}|q \\ &= (3.00 \times 10^4 \text{ N/C})(2.60 \times 10^{-9} \text{ C}) \\ &= 7.80 \times 10^{-5} \text{ N} \end{aligned}$$

d. This question is answered on the previous sketch.

$$\begin{aligned} \vec{F}_e &= \vec{F}_{\text{net}} \\ |\vec{F}_e| &= |\vec{F}_{\text{net}}| \\ |\vec{F}_e| &= ma \\ a &= \frac{|\vec{F}_e|}{m} \\ &= \frac{7.80 \times 10^{-5} \text{ N}}{4.24 \times 10^{-6} \text{ kg}} \\ &= 18.4 \text{ m/s}^2 \end{aligned}$$

$$\begin{aligned} \text{f. } v_f^2 &= v_i^2 + 2ad \\ v_f^2 &= 2ad \\ v_f &= \sqrt{2ad} \\ &= \sqrt{2(18.4 \text{ m/s}^2)(0.150 \text{ m})} \\ &= \sqrt{5.52 \text{ m}^2/\text{s}^2} \\ &= 2.35 \text{ m/s} \end{aligned}$$

4.



$$\sum E_{\text{before}} = \sum E_{\text{after}}$$

$$E_p + E_k = E_p' + E_k'$$

$$Fd + 0 = 0 + \frac{1}{2}mv'^2$$

$$v'^2 = \frac{2Fd}{m}$$

$$v' = \sqrt{\frac{2Fd}{m}}$$

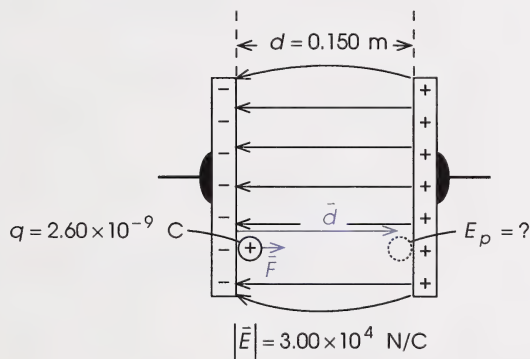
$$= \sqrt{\frac{2(7.80 \times 10^{-5} \text{ N})(0.150 \text{ m})}{(4.24 \times 10^{-6} \text{ kg})}}$$

$$= \sqrt{5.519 \text{ m}^2/\text{s}^2}$$

$$= 2.35 \text{ m/s}$$

5. The kinetic energy of the charged particle at the positive plate was assigned a zero value because the charge was initially at rest. The potential energy at the negative plate was assigned a zero value for convenience in solving this problem. Potential energy can be set to zero at any location.
6. The potential energy of a charge at a location can be given any number because it depends entirely on where the potential energy is assigned a zero value. In this case it was convenient to assign a value of zero potential energy to the charge at the negative plate so that it would have an easily calculated value at the positive plate.

7. a.



$$E_p = \text{work done on the charge}$$

$$= Fd$$

$$= F_e d$$

$$= q|\vec{E}|d$$

$$= (2.60 \times 10^{-9} \text{ C})(3.00 \times 10^4 \text{ N/C})(0.150 \text{ m})$$

$$= 1.17 \times 10^{-5} \text{ J}$$

- b. Since energy is conserved, the kinetic energy of the charge at the negative plate should be the same value of $1.17 \times 10^{-5} \text{ J}$.

$$8. \quad q = 2.60 \times 10^{-9} \text{ C}$$

$$\Delta E_p = 1.17 \times 10^{-5} \text{ J}$$

$$V = ?$$

$$\begin{aligned}
 V &= \frac{\Delta E_p}{q} \\
 &= \frac{(1.17 \times 10^{-5} \text{ J})}{(2.60 \times 10^{-9} \text{ C})} \\
 &= 4.50 \times 10^3 \text{ V}
 \end{aligned}$$

9. a. Battery A

$$\begin{aligned} q &= 1.00 \text{ } \mu\text{C} \\ \Delta E_p &= 6.00 \text{ } \mu\text{J} \\ V &= ? \end{aligned}$$

$$\begin{aligned} V &= \frac{\Delta E_p}{q} \\ &= \frac{(6.00 \text{ } \mu\text{J})}{(1.00 \text{ } \mu\text{C})} \\ &= 6.00 \text{ V} \end{aligned}$$

Battery B

$$\begin{aligned} q &= 1.00 \text{ mC} \\ \Delta E_p &= 6.00 \text{ mJ} \\ V &= ? \end{aligned}$$

$$\begin{aligned} V &= \frac{\Delta E_p}{q} \\ &= \frac{(6.00 \text{ mJ})}{(1.00 \text{ mC})} \\ &= 6.00 \text{ V} \end{aligned}$$

Battery C

$$\begin{aligned} q &= 1.00 \text{ C} \\ \Delta E_p &= 6.00 \text{ J} \\ V &= ? \end{aligned}$$

$$\begin{aligned} V &= \frac{\Delta E_p}{q} \\ &= \frac{(6.00 \text{ J})}{(1.00 \text{ C})} \\ &= 6.00 \text{ V} \end{aligned}$$

- b. The batteries all have the same potential difference. It could very well be that the batteries are identical, with battery B operating 1000 times longer than battery A and battery C operating 1000 times longer than battery B. This would explain the differences in both the amount of charge pumped and in the amount of energy increase.

10. The potential difference between two oppositely charged parallel plates is determined by the magnitude of the electric field between the plates and by the distance separating the two plates.

$$\begin{aligned} 11. \quad V &= \frac{\Delta E_p}{q} \\ &= \frac{Fd}{q} \\ &= \frac{|\vec{E}|qd}{q} \\ V &= |\vec{E}|d \end{aligned}$$

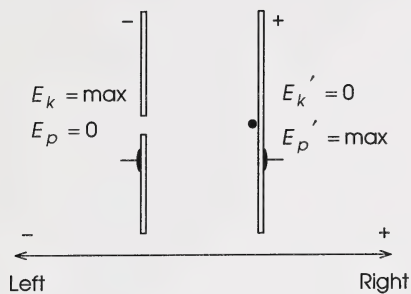
$$\begin{aligned} 12. \quad a. \quad d &= 0.150 \text{ m} \\ |\vec{E}| &= ? \\ V &= 4500 \text{ V} \end{aligned}$$

$$\begin{aligned} |\vec{E}| &= \frac{V}{d} \\ &= \frac{4500 \text{ V}}{0.150 \text{ m}} \\ &= 3.00 \times 10^4 \text{ V/m} \\ &= 3.00 \times 10^4 \text{ N/C} \end{aligned}$$

$$b. \quad 1 \frac{\text{V}}{\text{m}} = 1 \frac{\text{J}}{\text{C} \cdot \text{m}} = 1 \frac{\text{N} \cdot \text{m}}{\text{C} \cdot \text{m}} = 1 \frac{\text{N}}{\text{C}}$$

13. The solutions to these problems can be found on page 680 of your textbook.

14. a.



b. $\sum E_{\text{before}} = \sum E_{\text{after}}$

$$E_p + E_k = E'_p + E'_k$$

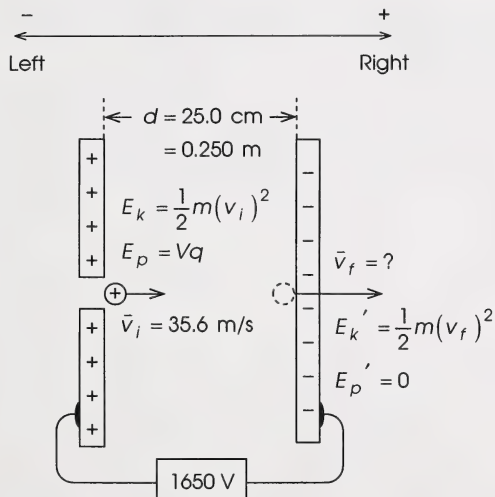
$$0 + \frac{1}{2}mv_i^2 = Vq + 0$$

$$V = \frac{\frac{1}{2}mv_i^2}{q}$$

$$= \frac{\frac{1}{2}(6.54 \times 10^{-6} \text{ kg})(35.6 \text{ m/s})^2}{3.75 \times 10^{-6} \text{ C}}$$

$$= 1.11 \times 10^3 \text{ V}$$

15. a.



- b. • Solve for v_f .

$$\begin{aligned}
 \sum E_{\text{before}} &= \sum E_{\text{after}} \\
 E_k + E_p &= E_k' + E_p' \\
 E_k + E_p &= E_k' + 0 \\
 E_k' &= E_k + E_p \\
 \frac{1}{2}m(v_f)^2 &= \frac{1}{2}m(v_i)^2 + Vq \\
 v_f &= \sqrt{\frac{\frac{1}{2}mv_i^2 + Vq}{\frac{1}{2}m}} \\
 &= \sqrt{\frac{\frac{1}{2}(6.54 \times 10^{-6} \text{ kg})(35.6 \text{ m/s})^2 + (1650 \text{ V})(3.75 \times 10^{-6} \text{ C})}{\frac{1}{2}(6.54 \times 10^{-6} \text{ kg})}} \\
 &= 56.2 \text{ m/s}
 \end{aligned}$$

- State the magnitude and direction of the final velocity.

$$\vec{v}_f = 56.2 \text{ m/s, right}$$

- c. • The electric force on the particle is unbalanced and causes it to accelerate according to Newton's second law. This can be used to calculate the acceleration.

$$\begin{aligned}
 \vec{F}_{\text{net}} &= \vec{F}_e \\
 |\vec{F}_{\text{net}}| &= |\vec{F}_e| \\
 ma &= q|\vec{E}| \\
 ma &= \frac{qV}{d} \\
 a &= \frac{qV}{md}
 \end{aligned}$$

- Combine the derived equation for acceleration with the given formula.

$$v_f^2 = v_i^2 + 2ad$$

$$v_f^2 = v_i^2 + 2\left(\frac{qV}{m\Delta x}\right)\Delta x$$

$$v_f = \sqrt{v_i^2 + \frac{2qV}{m}}$$

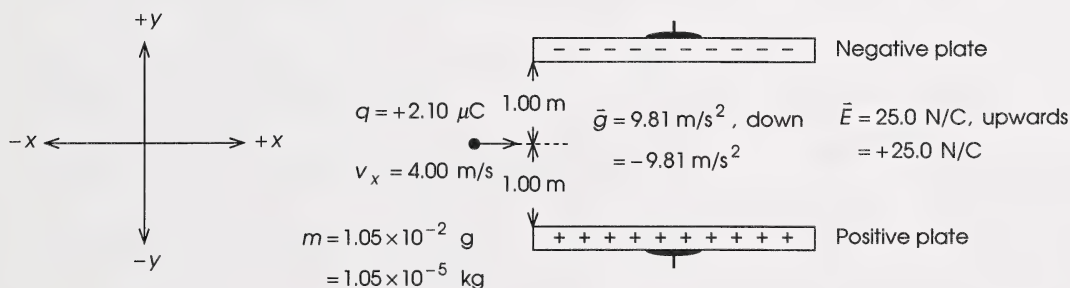
$$= \sqrt{(35.6 \text{ m/s})^2 + \frac{2(3.75 \times 10^{-6} \text{ C})(1650 \text{ V})}{6.54 \times 10^{-6} \text{ kg}}}$$

$$= 56.2 \text{ m/s}$$

- State the magnitude and direction of the final velocity.

$$\vec{v}_f = 56.2 \text{ m/s, right}$$

16. a.



- b. • The motion can be analysed from the point of view of projectile motion. The vertical motion will be accelerated due to the influence of the force of electricity and gravity. The horizontal motion will be uniform since no net force acts in this direction.

Vertical motion:

$$(v_y)_i = 0 \text{ m/s}$$

$$(v_y)_f = ?$$

$$d = -1.00 \text{ m}$$

$$|\vec{E}| = 25.0 \text{ N/C}$$

Horizontal motion:

$$v_x = 4.00 \text{ m/s}$$

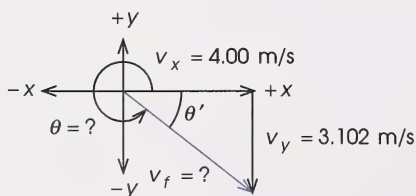
- Solve for the vertical acceleration of the particle.

$$\begin{aligned}
 \vec{F}_{net} &= \vec{F}_e + \vec{F}_g \\
 |\vec{F}_{net}| &= |\vec{F}_e|, \text{ up} + |\vec{F}_g|, \text{ down} \\
 |\vec{F}_{net}| &= +|\vec{F}_e| + -|\vec{F}_g| \\
 ma &= q|\vec{E}| - mg \\
 a &= \frac{q\vec{E} - mg}{m} \\
 &= \frac{(2.10 \times 10^{-6} \text{ C})(25.0 \text{ N/C}) - (1.05 \times 10^{-5} \text{ kg})(9.81 \text{ m/s}^2)}{(1.05 \times 10^{-5} \text{ kg})} \\
 &= -4.81 \text{ m/s}^2
 \end{aligned}$$

- Solve for the final vertical component of the velocity of the particle.

$$\begin{aligned}
 v_f^2 &= v_i^2 + 2ad \\
 (v_y)_f^2 &= (v_y)_i^2 + 2ad \\
 (v_y)_f^2 &= 0 + 2(-4.81 \text{ m/s}^2)(-1.00 \text{ m}) \\
 &= 9.62 \text{ m}^2/\text{s}^2 \\
 (v_y)_f &= 3.102 \text{ m/s} \\
 &= 3.10 \text{ m/s}
 \end{aligned}$$

- Solve for resultant velocity of the particle.



$$\begin{aligned}
 C^2 &= A^2 + B^2 \\
 v_f^2 &= v_x^2 + v_y^2 \\
 &= (4.00 \text{ m/s})^2 + (3.102 \text{ m/s})^2 \\
 &= 25.62 \text{ m}^2/\text{s}^2 \\
 v_f &= 5.06 \text{ m/s}
 \end{aligned}$$

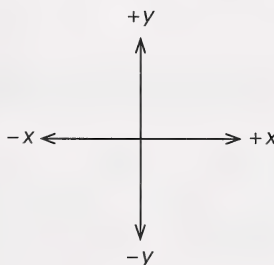
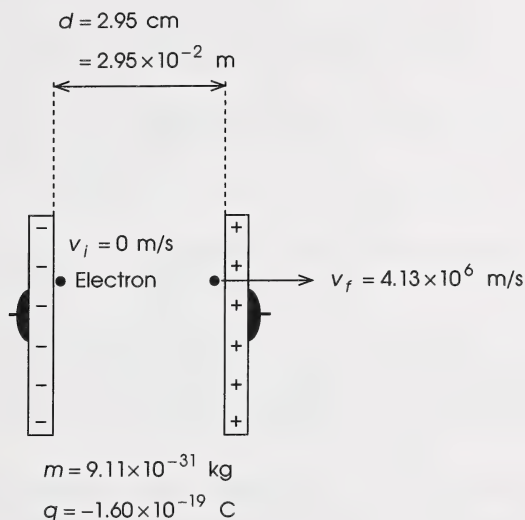
$$\begin{aligned}
 \tan \theta' &= \frac{3.102 \text{ m/s}}{4.00 \text{ m/s}} \\
 &= 0.7755 \\
 \theta' &= 37.8^\circ
 \end{aligned}$$

$$\begin{aligned}
 \theta &= 360^\circ - \theta' \\
 &= 360^\circ - 37.8^\circ \\
 &= 322.2^\circ \\
 &= 322^\circ
 \end{aligned}$$

- The final velocity of the particle is 5.06 m/s, 322°.

- c. As was shown in the solution to question 16. b., the net acceleration and net force would move the particle down to the positive plate.

17. a.



Gravity will not be a consideration for a particle this small.

- b. Apply the law of conservation of energy.

$$\begin{aligned}
 \sum E_{\text{before}} &= \sum E_{\text{after}} \\
 E_p + E_k &= E_p' + E_k' \\
 Vq + 0 &= 0 + \frac{1}{2} m (v_f)^2 \\
 V &= \frac{\frac{1}{2} m (v_f)^2}{q} \\
 &= \frac{\frac{1}{2} (9.11 \times 10^{-31} \text{ kg}) (4.13 \times 10^6 \text{ m/s})^2}{(1.60 \times 10^{-19} \text{ C})} \\
 &= 48.56 \text{ V} \\
 &= 48.6 \text{ V}
 \end{aligned}$$

$$\begin{aligned}
 \text{c. } |\vec{E}| &= \frac{V}{d} \\
 &= \frac{(48.56 \text{ V})}{(2.95 \times 10^{-2} \text{ m})} \\
 &= 1646 \text{ V/m} \\
 &= 1.65 \times 10^3 \text{ N/C}
 \end{aligned}$$

Note that only the magnitude of the charge was substituted into the equation.

$$d. \quad F_{net} = ma$$

$$a = \frac{F_{net}}{m}$$

$$= \frac{|\vec{E}|q}{m}$$

$$= \frac{(1.646 \times 10^3 \text{ N/C})(1.60 \times 10^{-19} \text{ C})}{9.11 \times 10^{-31} \text{ kg}}$$

$$= 2.89 \times 10^{14} \text{ m/s}^2$$

OR

$$v_f^2 = v_i^2 + 2ad$$

$$a = \frac{v_f^2 - v_i^2}{2d}$$

$$= \frac{(4.13 \times 10^6 \text{ m/s})^2 - 0}{2(2.95 \times 10^{-2} \text{ m})}$$

$$= 2.89 \times 10^{14} \text{ m/s}^2$$

18. The conductors must be at the same potential in order for charge to stop flowing between them. In other words the potential difference between them must be zero.
19. If two conductors have the same potential difference with respect to the ground, it took the same amount of work to move the charges from the ground to each conductor. Since potential difference is the change in potential energy per charge, if one conductor happens to have twice as many charges, it will take twice as much work to move those charges. The result is that the ratio of change in potential energy per charge remains the same. The answer to question 9 illustrates this point with batteries.
20. Grounding involves touching an object to the earth with a conductor so that any excess charge on the object will flow to the earth. The earth is such a large object that these excess charges make no measurable difference on the net charge of the planet. Once an object is grounded, there is no potential difference between itself and the earth, and so the charges that do remain have no reason to move further.
21. Both the jet airliner and the truck have to push large quantities of air out of the way when they move. This produces a transfer of charge between the exterior metal parts and the air due to friction. The large rubber tires prevent the charge from being grounded. Since these objects are so large, it is possible for them to acquire enough charge to produce a spark if they were suddenly touched to another conductor. Since jet fuel is extremely flammable, both objects are grounded to help prevent sparks that could ignite the vapours.
22. Computer chips are very delicate devices that are designed to run with very small amounts of charge at low voltage. It is possible for a person's body to accumulate enough charge to cause an energy surge that does permanent damage just by touching it. When the student touched the large metal legs of the computer table, excess charge was allowed to flow harmlessly to the table legs.

Section 1: Activity 3

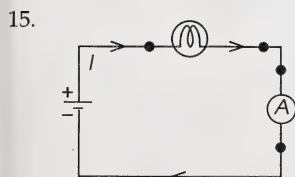
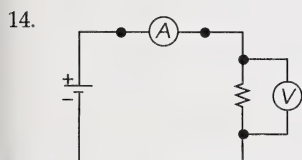
1. An electric current is defined as the flow of charge past a point per unit of time.
2. The protons, which are the positive charges, are in the nucleus. They don't move in a metal conductor. Only the loosely held electrons move.
3. a. Diagram A illustrates electron flow because the negatively charged electrons are attracted to the positive end of the battery. Diagram B illustrates conventional current because it shows that there is movement from the positive end to the negative end of the battery.

b. Diagram B represents what physicists would call current.

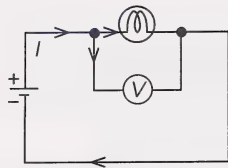
4. Physicists have a hard time changing to a new system of naming things. Another reason is that both potential difference and electric field are defined in terms of positive charges, so in many cases it is easier to think of current the same way.
5. An electric circuit is a closed loop in which charges have their potential energy raised in one part and lowered in another part.
6. The battery does not make new charges. It only increases the potential energy of the existing charges. Charge is conserved.
7. An ampere is the flow of 1 C of charge past a point in 1 s.
8. Since the unit for electric current, the ampere, is equal to the number of coulombs divided by the number of seconds, current should be defined as the number of charges that pass in a given time.

$$1 \text{ A} = \frac{1 \text{ C}}{1 \text{ s}} \Rightarrow \text{Current} = \frac{\text{Charge}}{\text{Time}} \Rightarrow I = \frac{q}{t}$$

9. The solutions to these problems can be found on page 681 of your textbook.
10. An ammeter measures the amount of current that flows past a point.
11. A voltmeter measures the potential difference across a device.
12. A series connection means that there is only one path for the current. Measuring the current with an ammeter is an example of a series connection.
13. A parallel connection means that there is more than one path for the current. Measuring the potential difference (voltage) with a voltmeter is an example of a parallel connection.



16.



17. $V = 1.55 \text{ V}$

$I = 25 \text{ mA} = 2.5 \times 10^{-2} \text{ A}$

$P = IV$

$= (2.5 \times 10^{-2} \text{ A})(1.55 \text{ V})$

$= 3.9 \times 10^{-2} \text{ W}$

18. $I = 2.5 \times 10^{-2} \text{ A}$

$t = 1.00 \text{ s}$

$q = ?$

$I = \frac{q}{t}$

$q = It$

$= (2.5 \times 10^{-2} \text{ A})(1.00 \text{ s})$

$= 2.5 \times 10^{-2} \text{ C}$

19. $q = 1.00 \text{ C}$

$V = 1.55 \text{ V}$

$\Delta E = ?$

$V = \frac{\Delta E}{q}$

$\Delta E = qV$

$= (1.00 \text{ C})(1.55 \text{ V})$

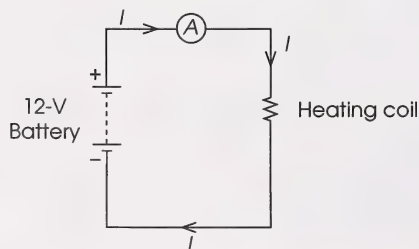
$= 1.55 \text{ J}$

20. In question 19 you found that there was 1.55 J/C . In question 18 you found the number of coulombs present: $2.5 \times 10^{-2} \text{ C}$.

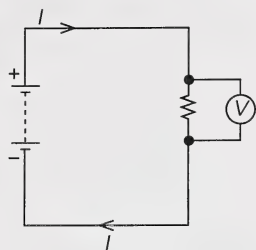
$E = \left(\frac{1.55 \text{ J}}{\text{C}} \right) (2.5 \times 10^{-2} \text{ C})$

$= 3.9 \times 10^{-2} \text{ J in } 1 \text{ s}$

21.



22.



23. $V = 12.1 \text{ V}$

$P = 200 \text{ W}$

$I = ?$

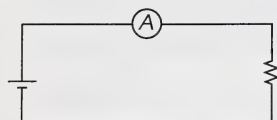
$P = IV$

$$I = \frac{P}{V}$$

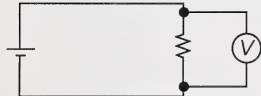
$$= \frac{200 \text{ W}}{12.1 \text{ V}}$$

$$= 16.5 \text{ A}$$

24.



25.



26. You should use the 4.34-V value because that is what the actual potential difference (voltage) is. The 4.5-V marking is a rough scale on the power supply.

27. $V = 4.34 \text{ V}$

$P = IV$

$I = 8.52 \text{ mA} = 8.52 \times 10^{-3} \text{ A}$

$$= (8.52 \times 10^{-3} \text{ A})(4.34 \text{ V})$$

$$= 3.70 \times 10^{-2} \text{ W}$$

28. a. When measuring the current, the multimeter should make a series connection with the resistor. Also the positive lead should be moved into the input for measuring current.

b. When measuring the current, the multimeter should make a series connection with the resistor.

c. There is no current because there must be a break or bad contact somewhere in the circuit. It could also mean that the fuse has blown.

d. The multimeter has to be connected across the resistor (making a parallel connection). Also the positive lead is not plugged into the voltmeter section.

- e. The polarity of the connection is reversed. The negative lead connected to the COM plug should be connected to the negative output of the power supply. The positive lead should be the closest one to the positive output of the power supply.
29. You should always double check the setting of the dial on the meter, the position of the input leads, and whether the circuit has the meter connected in series or parallel.

Section 1: Activity 4

Investigation: Measuring Potential Difference and Current for a Resistor

The following are data charts like those you should have copied into your notebook. The values are sample values. Your values may differ from those shown, but the trends should be the same.

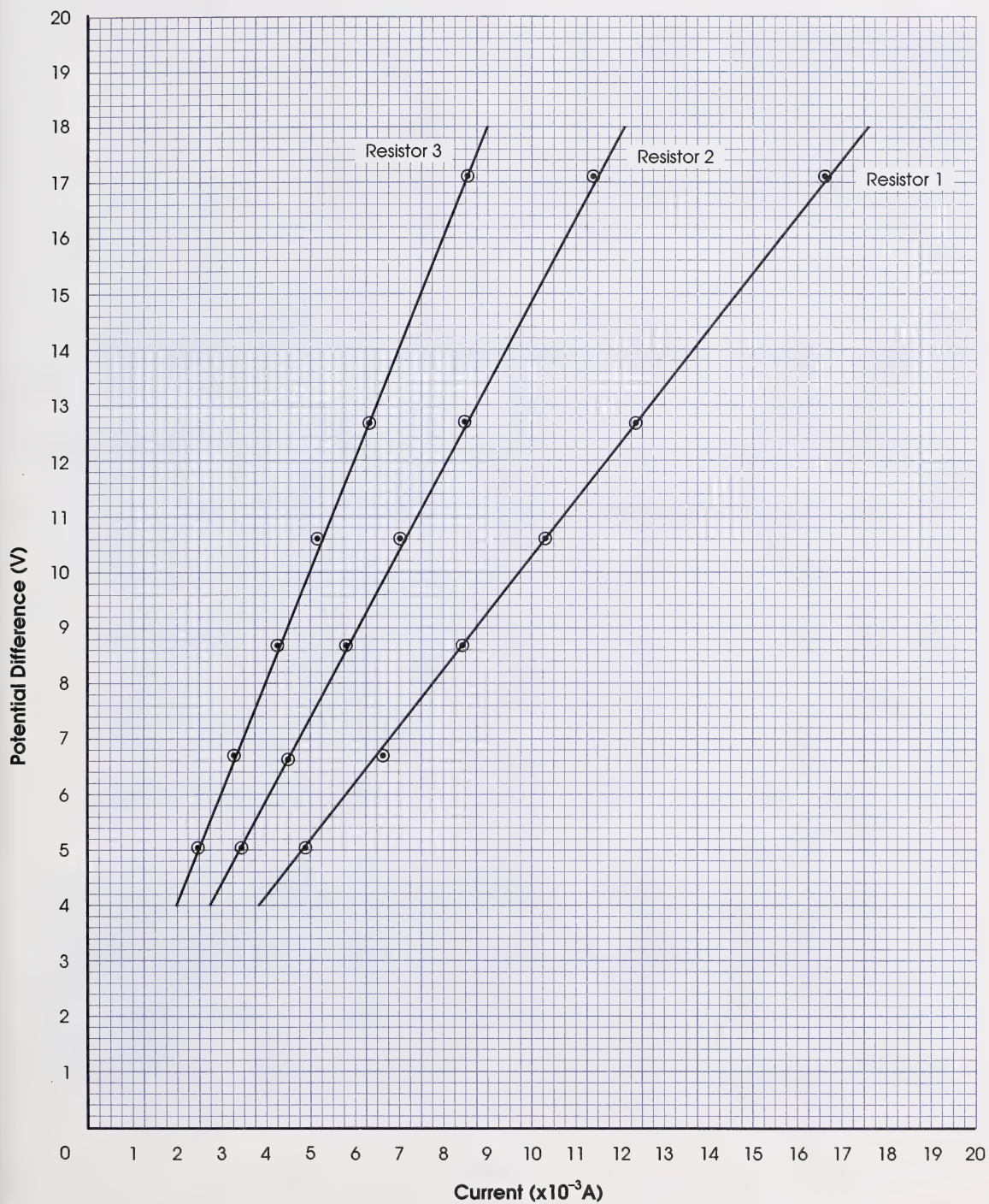
Resistor 1	
V (volts)	I ($\times 10^{-3}$ A)
5.1	4.9
6.7	6.5
8.7	8.4
10.6	10.3
12.7	12.4
17.1	16.7

Resistor 2	
V (volts)	I ($\times 10^{-3}$ A)
5.1	3.4
6.7	4.5
8.7	5.8
10.6	7.1
12.7	8.5
17.1	11.4

Resistor 3	
V (volts)	I ($\times 10^{-3}$ A)
5.1	2.5
6.7	3.3
8.7	4.3
10.6	5.2
12.7	6.3
17.1	8.6

1. a. The graph shown on the next page contains the answers for questions 1 through 3.

Potential Difference vs. Current



b. This question is answered on the previous graph.

$$\begin{aligned}
 \text{c. slope} &= \frac{\text{rise}}{\text{run}} \\
 &= \frac{15.8 \text{ V} - 9.0 \text{ V}}{15.5 \text{ mA} - 8.75 \text{ mA}} \\
 &= \frac{6.8 \text{ V}}{6.75 \text{ mA}} \\
 &= \frac{6.8 \text{ V}}{6.75 \times 10^{-3} \text{ A}} \\
 &= 1007 \text{ V/A} \\
 &= 1.0 \times 10^3 \text{ V/A}
 \end{aligned}$$

2. a. This question is answered on the previous graph.

b. This question is answered on the previous graph.

$$\begin{aligned}
 \text{c. slope} &= \frac{\text{rise}}{\text{run}} \\
 &= \frac{17.8 \text{ V} - 4.0 \text{ V}}{12.0 \times 10^{-3} \text{ A} - 2.75 \times 10^{-3} \text{ A}} \\
 &= \frac{13.8 \text{ V}}{9.25 \times 10^{-3} \text{ A}} \\
 &= 1492 \text{ V/A} \\
 &= 1.5 \times 10^3 \text{ V/A}
 \end{aligned}$$

3. a. This questions is answered on the previous graph.

b. This question is answered on the previous graph.

$$\begin{aligned}
 \text{c. slope} &= \frac{\text{rise}}{\text{run}} \\
 &= \frac{17.5 \text{ V} - 5.0 \text{ V}}{8.75 \times 10^{-3} \text{ A} - 2.5 \times 10^{-3} \text{ A}} \\
 &= \frac{12.5 \text{ V}}{6.25 \times 10^{-3} \text{ A}} \\
 &= 2000 \text{ V/A} \\
 &= 2.0 \times 10^3 \text{ V/A}
 \end{aligned}$$

4. The resistors had the following values:

- $R_1 = 1007 \ \Omega$
- $R_2 = 1492 \ \Omega$
- $R_3 = 2000 \ \Omega$

5. The relationship between the potential difference and the current is that they are directly proportional. According to the graph, it is a straight line. Therefore,

$$y = mx + b$$

Slope

y -intercept: For these graphs the y -intercept is very close to zero in each case. This makes sense because if the current has a zero value, there is no reason for charges to flow because there is no potential difference. If the y -intercept is assumed to be zero, the equation simplifies as shown.

$$y = mx + b$$

By inspection

$$V = R I + 0$$

$$V = RI$$

6. The unit of resistance is called an ohm to honour the German scientist, Georg Simon Ohm, who measured the resistance of many conductors.
7. In order for a statement to be called a law, it has to apply to a wide variety of circumstances. His law applies over a limited range of voltages for mostly metallic conductors and no other substances.
8. Current can be controlled by adjusting either the potential difference or the resistance of the circuit.
9. A potentiometer is a variable resistor. A dimmer switch on a light fixture might use a potentiometer. Potentiometers can also be found in the speed controls of electric fans and mixers.

10. Dry Wet

$$\begin{aligned} I &= \frac{V}{R} \\ &= \frac{120 \text{ V}}{1 \times 10^5 \Omega} \\ &= 1 \times 10^{-3} \text{ A} \\ &= 1 \text{ mA} \end{aligned}$$

$$\begin{aligned} I &= \frac{V}{R} \\ &= \frac{120 \text{ V}}{1500 \, \Omega} \\ &= 8.00 \times 10^{-2} \text{ A} \\ &= 80.0 \text{ mA} \end{aligned}$$

- 11.

Effects of Current on the Human Body					
Current	2 mA	10 to 20 mA	20 mA	20 to 100 mA	100 mA to 3A
Effect	feel a tingle	muscular effects	can't let go of conducting wire	respiratory paralysis	fatal

12. The solutions to these problems can be found on page 681 of your textbook.
13. The solutions to these problems can be found on pages 681 and 682 of your textbook.
14. The solutions to these problems can be found on page 682 of your textbook.
15. The answers to these problems can be found on page 674 of your textbook.
16. The answer to this problem can be found on page 682 of your textbook.
17. **Materials**

The materials are divided into two parts. The first part is the electrical section, which is the electric circuit, and the second part is the calorimeter, where the transfer of energy is measured.

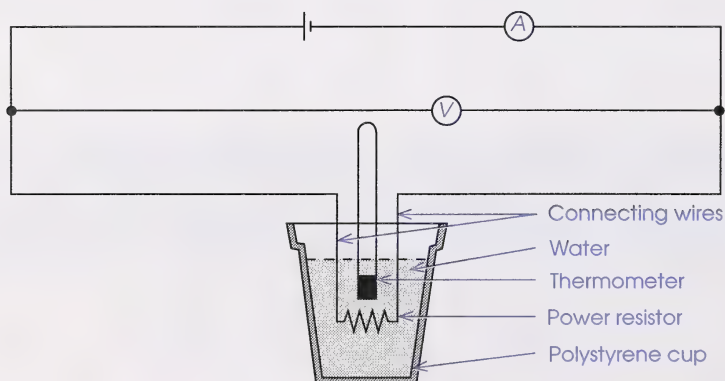
The electric section

- a DC power supply capable of 0 V to 5 V and 0 A to 1 A
- an ammeter with a range of 0 A to 5 A
- a voltmeter with a range of 0 V to 20 V
- a $30\text{-}\Omega$ power resistor rated at 5 W power handling
- wires
- a switch

The calorimeter section

- a covered polystyrene cup which can hold 50 mL of water
- a thermometer with a range of 15°C to 40°C
- a 50-mL graduated cylinder
- water

The following schematic diagram shows how to set up the apparatus for this investigation.



Important Safety Precautions

It is very important that you read and apply the information in these safety warnings before you begin this investigation. Injury or death can occur even with low voltages and low currents.

- Never ground yourself while working with a live circuit. Do not touch metal pipes, electrical outlets, light fixtures, etc., that might be grounded. Be sure to keep your body insulated by keeping your hands and body dry and by wearing dry clothing and running shoes.
- Only replace the fuse inside the meter with the specified or approved equivalent fuse.
- Use the meter only as specified in the investigation. Do not use the meter to test a wall outlet or an electric appliance. If you try to measure a voltage that exceeds the limits of the meter, you may damage the meter and expose yourself to a serious electric shock.
- Resistors can become warm and in some cases hot enough to cause burns. Always disconnect a recently used resistor and allow it to cool for a few minutes before handling.

You will ensure your own safety by applying this information as you complete the investigation.

Procedure

- The apparatus was set up as shown in the previous diagram. The amount of water in the container was 50.0 mL, or approximately 50.0 g.
- It is important to keep the area dry, as wet skin has a lower resistance than dry skin. It is also important not to touch any metal pipes, sinks, faucets, or other objects while completing this experiment, as you could become part of a circuit when excess charge transfers to ground.
- The initial temperature (T_i) will be noted before starting.
- After closing the switch, the timer was started and the initial current (I_i) and voltage (V_i) were recorded.
- After 10 min, the final current (I_f) and voltage (V_f) were recorded.

Data

	Temperature (°C)	Current (A)	Voltage (V)	Electric Energy (J)	Thermal Energy (J)
Initial	22	2.2	2.6	3.4×10^3	2.7×10^3
Final	35	2.1	2.6		

Sample Calculations

mass of water (m) = 50.0 g = 0.0500 kg

time for heating (t) = 10.0 min = 600 s

specific heat capacity for water (c) = 4180 J/kg • °C

Calculation of electric energy:

$$P = \frac{E}{t}$$

$$E = Pt$$

$$= IVt$$

$$= (2.15 \text{ A})(2.6 \text{ V})(600 \text{ s})$$

$$= 3354 \text{ J}$$

$$= 3.4 \times 10^3 \text{ J}$$

Calculation of thermal energy:

$$Q = mc\Delta T$$

$$= (0.0500 \text{ kg})(4180 \text{ J/kg} \cdot ^\circ\text{C})(13^\circ\text{C})$$

$$= 2717 \text{ J}$$

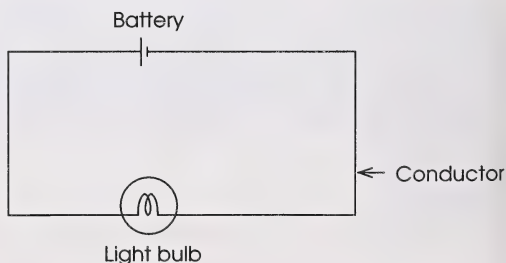
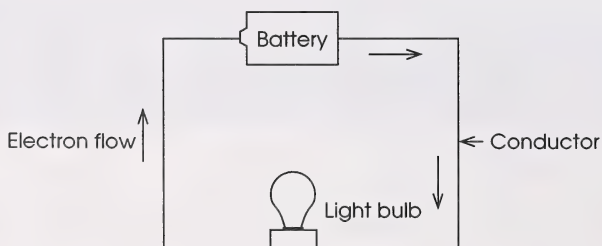
$$= 2.7 \times 10^3 \text{ J}$$

Section 1: Follow-up Activities

Extra Help

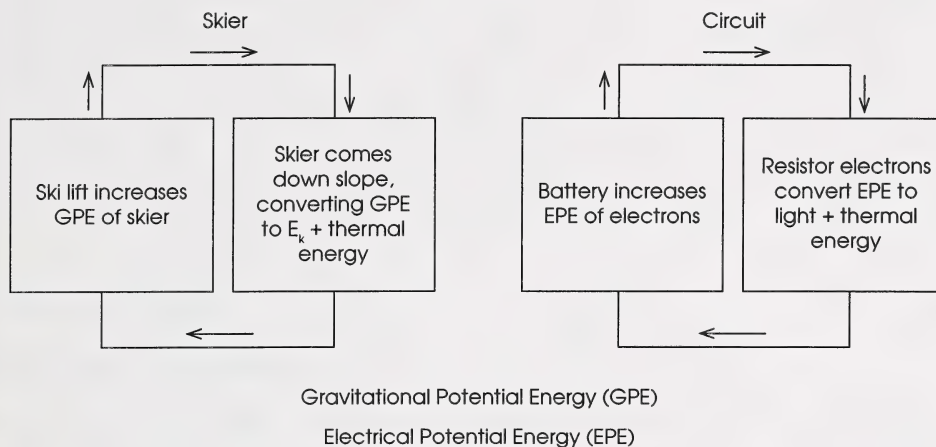
- At the time of Benjamin Franklin, electrons were not yet discovered.
- There was an imbalance in the potential and a flow of charge occurred until it was balanced. The same amount of charge will collect on each sphere since the spheres are identical.
- They are called electrodes. A battery has a negative electrode made of zinc (outside casing) and a positive electrode made of carbon (middle rod).
- The process begins in the battery where chemical energy is converted to electric potential energy. The outcome of this chemical reaction is that electrons are supplied to the zinc outer casing of the battery. These electrons are then able to flow along a conducting wire with little or no resistance. However, when the electrons encounter the filament of the light bulb, electric potential energy is converted to thermal energy and light. These low-energy electrons are then pulled back to the battery where they are re-energized for another trip around the circuit. Since charge is conserved, the battery simply acts like a pump to re-energize and circulate the charges.

5.



6. In a direct current electrons flow continuously in only one direction. In an alternating current electrons vibrate and change direction repeatedly.

7.



8. a. There is a loss of electric potential energy from A to B.
 b. There is a gain of electric potential energy from C to D.
 c. There are minimum changes in electric potential energy from D to A and from B to C.
9. A wire is a good conductor of electrons. A resistor is a poor conductor of electrons. Electrons are not easily moved in a resistor.
10. The electric potential energy is changed to light and thermal energy.
11. The resistance does not change. It is an inherent property of the resistor.
12. The difference is that the brighter light bulb has more resistance.

Enrichment

1. Georg Simon Ohm was born the son of a mechanic in Erlangen, Bavaria in 1787. Ohm was a high school teacher who wanted to teach at a university, but in order to do this he had to first publish some important research work. Ohm decided to study one of the most exciting new scientific fields of this time – current electricity. Ohm focused on exploring the relationship between the potential difference across a conductor and the resulting electric current that flowed through it. His results could be summed up in the equation now known as Ohm's law ($V = IR$).

Unfortunately, the scientists of his day were very critical of his work and would not accept his results. The criticism was so severe that he was forced to resign his position as a high school teacher and had to live the next six years in poverty. As time passed, his work became known outside of Germany and scientists in other countries began to honour his work and accomplishments. Eventually, he was asked to teach at the university of Munich, where he taught for the last five years of his life.

His work is honoured to this day by naming the unit of resistance the ohm.

2. a. These questions are answered on page 681 of your textbook.

b. Textbook question 22:

$$C = 10.0 \text{ } \mu\text{F} = 10.0 \times 10^{-6} \text{ F}$$

$$V = 3.00 \times 10^2 \text{ V}$$

$$W = ?$$

$$W = \frac{1}{2} CV^2$$

$$= \frac{1}{2} (10.0 \times 10^{-6} \text{ F}) (3.00 \times 10^2 \text{ V})^2$$

$$= 0.450 \text{ J}$$

Textbook question 23. a.:

$$t = 30 \text{ s}$$

$$W = 0.450 \text{ J}$$

$$P = ?$$

$$P = \frac{W}{t}$$

$$= \frac{0.450 \text{ J}}{30 \text{ s}}$$

$$= 0.015 \text{ W}$$

Textbook question 23. b.:

$$t = 1.0 \times 10^{-4} \text{ s}$$

$$W = 0.450 \text{ J}$$

$$P = ?$$

$$P = \frac{W}{t}$$

$$= \frac{0.450 \text{ J}}{1.0 \times 10^{-4} \text{ s}}$$

$$= 4.5 \times 10^3 \text{ W}$$

Textbook question 23. c.:

The large power is possible because the time interval is so small.

Textbook question 24. a.:

$$C = 61 \times 10^{-3} \text{ F}$$

$$V = 10 \text{ kV} = 10 \times 10^3 \text{ V}$$

$$W = ?$$

$$W = \frac{1}{2} CV^2$$

$$= \frac{1}{2} (61 \times 10^{-3} \text{ F}) (10 \times 10^3 \text{ V})^2$$

$$= 3.05 \times 10^6 \text{ J}$$

$$= 3.1 \times 10^6 \text{ J}$$

Textbook question 24. b.:

$$t = 10 \text{ ns} = 1.0 \times 10^{-8} \text{ s}$$

$$W = 3.1 \times 10^6 \text{ J}$$

$$P = ?$$

$$P = \frac{W}{t}$$

$$= \frac{3.1 \times 10^6 \text{ J}}{1.0 \times 10^{-8} \text{ s}}$$

$$= 3.1 \times 10^{14} \text{ W}$$

Textbook question 24. c.:

$$W = 3.1 \times 10^6 \text{ J}$$

$$P = 1.0 \text{ kW} = 1.0 \times 10^3 \text{ W}$$

$$t = ?$$

$$P = \frac{W}{t}$$

$$t = \frac{W}{P}$$

$$= \frac{3.1 \times 10^6 \text{ J}}{1.0 \times 10^3 \text{ W}}$$

$$= 3100 \text{ s}$$

$$= 3.1 \times 10^3 \text{ s}$$

Section 2: Activity 1

Investigation: The Series Circuit

The following is a sample data chart like the one that you should have copied into your notebook.

$$R_{1+2+3} = 3000 \Omega$$

$$R_{1+2} = 1516 \Omega$$

$$R_1 = 506 \Omega$$

$$R_2 = 1010 \Omega$$

$$R_3 = 1480 \Omega$$

$$V_1 = 2.85 \text{ V}$$

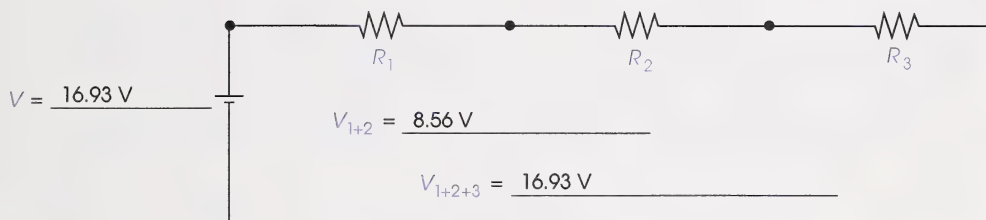
$$V_2 = 5.71 \text{ V}$$

$$V_3 = 8.37 \text{ V}$$

$$I_1 = 5.6 \text{ mA}$$

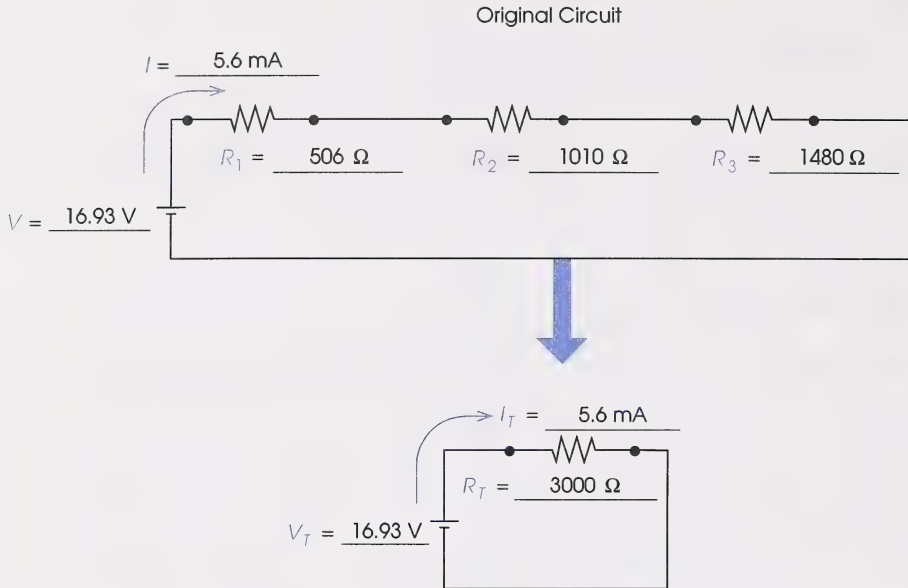
$$I_2 = 5.6 \text{ mA}$$

$$I_3 = 5.6 \text{ mA}$$



1. The voltage output of the power supply used to collect the sample data is 16.93 V.
2. The sum of the individual voltage drops across each resistor is equal to the total voltage output of the power supply.
3. The electric potential energy of the electrons are raised to a certain level in the power supply and then this electric potential energy is used up by each of the resistors. In other words, there is conservation of energy.
4. The current is the same through each resistor. The individual currents are equal to the current output of the power supply.

5. There is only one path for the current to flow and that is why the current is the same throughout the whole circuit.
6. The sum of the individual values for resistance is equal to the total resistance of the circuit.
- 7.



$$\begin{aligned}
 8. \quad R_T &= \frac{V_T}{I_T} \\
 &= \frac{16.93 \text{ V}}{5.6 \text{ mA}} \\
 &= \frac{16.93 \text{ V}}{5.6 \times 10^{-3} \text{ A}} \\
 &= 3023 \, \Omega \\
 &= 3.0 \times 10^3 \, \Omega
 \end{aligned}$$

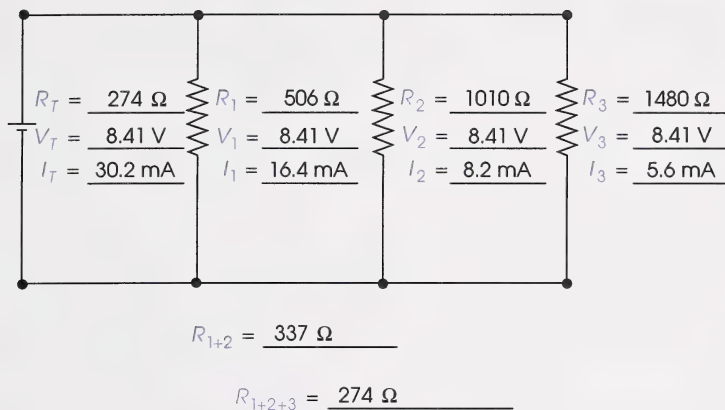
The theoretical value is close to the measured value. The difference is only $23 \, \Omega$, which is less than a 1% error.

9. An equivalent resistance is the value of a single resistor that could replace a group of resistors in a circuit and not change the current flowing through the circuit.
10. Refer to the answers on page 682 in your textbook.
11. Refer to the answers on page 682 in your textbook.

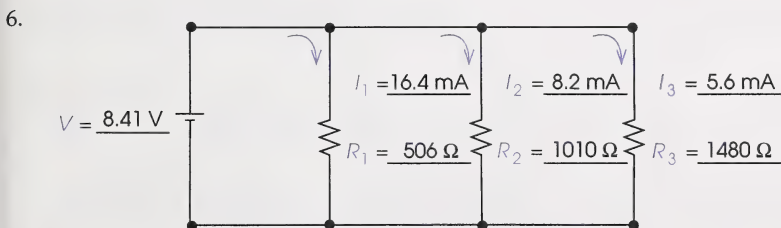
Section 2: Activity 2

Investigation: The Parallel Circuit

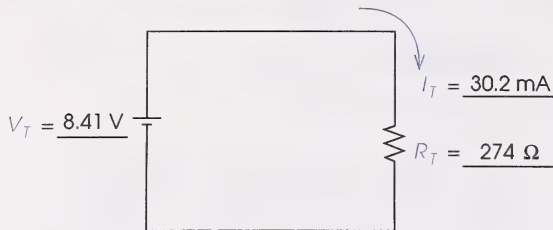
The following is a sample data chart like the one that you should have copied into your notebook.



1. The sum of the individual voltage drops across each resistor equals the voltage output of the power supply.
2. The potential drop across each path is the same because the battery does a certain amount of work to the electrons and, regardless of the path they take, the electrons must lose all of that energy by the time they reach the battery. Therefore, each path has the same drop in electric potential difference.
3. The total current provided by the power supply is equal to the sum of the individual currents in the branches.
4. The total current equals the sum of the currents in each branch because charge is conserved.
5. The total resistance of all three resistors connected in parallel is less than the individual resistances of all the three resistors.



If all the resistors were replaced with an equivalent single resistor, R_T , so that the total current did not change, the circuit would look like this.



$$\begin{aligned}
 7. \quad R_T &= \frac{V_T}{I_T} \\
 &= \frac{8.41 \text{ V}}{30.2 \text{ mA}} \\
 &= \frac{8.41 \text{ V}}{30.2 \times 10^{-3} \text{ A}} \\
 &= 278 \, \Omega
 \end{aligned}$$

The theoretical and actual values are very close. Their difference is only $4 \, \Omega$, giving a percent error of less than 2%.

$$\begin{aligned}
 8. \quad \frac{1}{R_T} &= \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \\
 &= \frac{1}{506 \, \Omega} + \frac{1}{1010 \, \Omega} + \frac{1}{1480 \, \Omega} \\
 R_T &= 275 \, \Omega
 \end{aligned}$$

The measured value and the calculated value are nearly the same. The difference is only $1 \, \Omega$, giving a percent error of less than 1%.

9. Refer to the answers on page 682 in your textbook.
10. The household wiring is a certain standard size (gauge) designed for a maximum current. If too much current passes through the wire, the wire will get too hot and a fire will result.
11. A fuse melts when the current through it is so large that the $I^2 R$ heating melts the element. By melting, the fuse breaks the circuit, and no current flows.
12. Circuit breakers do not melt. They have a metal strip which expands as it heats. This strip eventually causes the circuit breaker to “flip” and the switch inside the breaker opens and the current is stopped.
13. The ground fault interrupter (or GFI) is a device that contains a tiny electronic circuit for detecting tiny surges in current due to an appliance being improperly grounded. The GFI will automatically open the circuit, preventing further current from flowing and preventing dangerous electric shocks.
14. A short circuit occurs when two wires cross and the path of the current is shortened. Since the normal source of resistance is no longer in the circuit, a very large current is drawn.

Section 2: Activity 3

1. Refer to page 683 in your textbook for answers.

$$\begin{array}{rcl}
 2. \quad I_1 & = & 3.00 \text{ A} \\
 I_2 & = & 1.20 \text{ A} \\
 I_3 & = & 1.80 \text{ A}
 \end{array}
 \qquad
 \begin{array}{rcl}
 \sum I_{in} & = & \sum I_{out} \\
 I_2 + I_3 & = & I_1 \\
 1.20 \text{ A} + 1.80 \text{ A} & = & 3.00 \text{ A} \\
 3.00 \text{ A} & = & 3.00 \text{ A}
 \end{array}$$

These values verify that the currents follow Kirchoff's junction rule.

$$\begin{array}{rcl}
 3. \quad \sum I_{in} & = & \sum I_{out} \\
 I_1 & = & I_2 + I_3
 \end{array}$$

4. Since charge is conserved, in a given time interval the sum of the charges entering a junction must equal the sum of the charges leaving the junction.

5. At the battery the charges gain potential energy, while at the resistors the charges lose potential energy.

$$\begin{array}{rcl}
 6. \quad V & = & V_1 + V_2 \\
 & = & (24 \text{ V}) + (36 \text{ V}) \\
 & = & 60 \text{ V}
 \end{array}
 \qquad
 \begin{array}{l}
 \text{This is the value of the potential difference supplied by the source.}
 \end{array}$$

$$\begin{array}{rcl}
 7. \quad V & = & V_1 + V_3 \\
 & = & (24 \text{ V}) + (36 \text{ V}) \\
 & = & 60 \text{ V}
 \end{array}
 \qquad
 \begin{array}{l}
 \text{This is the value of the potential difference supplied by the source.}
 \end{array}$$

8. The answer to the previous question is consistent with what is printed in the textbook.

9. a. Apply Kirchoff's junction rule to junction A.

$$\begin{array}{rcl}
 \sum I_{in} & = & \sum I_{out} \\
 I_1 & = & I_2 + I_3 \\
 I_2 & = & I_1 - I_3 \\
 & = & 0.50 \text{ A} - 0.20 \text{ A} \\
 & = & 0.30 \text{ A}
 \end{array}$$

$$\begin{array}{rcl}
 b. \quad \sum V & = & 0 \\
 V_2 - V_3 & = & 0 \\
 V_2 & = & V_3 \\
 I_2 R_2 & = & I_3 R_3 \\
 I_2 & = & \frac{I_3 R_3}{R_2} \\
 & = & \frac{(0.20 \text{ A})(7.5 \Omega)}{(5.0 \Omega)} \\
 & = & 0.30 \text{ A}
 \end{array}$$

$$\begin{aligned}
 \text{c.} \quad \sum V &= 0 \\
 V - V_1 - V_3 &= 0 \\
 V &= V_1 + V_3 \\
 &= I_1 R_1 + I_3 R_3 \\
 &= (0.50 \text{ A})(3.0 \, \Omega) + (0.20 \text{ A})(7.5 \, \Omega) \\
 &= 1.5 \text{ V} + 1.5 \text{ V} \\
 &= 3.0 \text{ V}
 \end{aligned}$$

$$\begin{aligned}
 \text{d.} \quad \sum V &= 0 \\
 V - V_1 - V_2 &= 0 \\
 V &= V_1 + V_2 \\
 &= I_1 R_1 + I_2 R_2 \\
 &= (0.50 \text{ A})(3.0 \, \Omega) + (0.30 \text{ A})(5.0 \, \Omega) \\
 &= 1.5 \text{ V} + 1.5 \text{ V} \\
 &= 3.0 \text{ V}
 \end{aligned}$$

10. a. Apply Kirchhoff's loop rule to the loop containing R_2 and R_3 .

$$\begin{aligned}
 \sum V &= 0 \\
 V_2 - V_3 &= 0 \\
 V_2 &= V_3 \\
 I_2 R_2 &= I_3 R_3 \\
 I_2 &= \frac{I_3 R_3}{R_2} \\
 &= \frac{(50 \text{ mA})(20 \, \Omega)}{(10 \, \Omega)} \\
 &= 100 \text{ mA} \\
 &= 1.0 \times 10^{-1} \text{ A}
 \end{aligned}$$

- b. Apply Kirchhoff's junction rule to junction A.

$$\begin{aligned}
 \sum I_{in} &= \sum I_{out} \\
 I_1 &= I_2 + I_3 \\
 &= (100 \text{ mA}) + (50 \text{ mA}) \\
 &= 150 \text{ mA} \\
 &= 1.5 \times 10^{-1} \text{ A}
 \end{aligned}$$

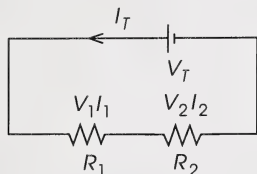
- c. Apply Kirchhoff's loop rule to the loop containing V , R_1 , R_2 and R_4 . Since R_4 is in series with R_1 , they both pass the same current. Therefore, $I_4 = I_1 = 150 \text{ mA} = 0.150 \text{ A}$.

$$\begin{aligned}
 \sum V &= 0 \\
 V - V_1 - V_2 - V_4 &= 0 \\
 V &= V_1 + V_2 + V_4 \\
 &= (I_1 R_1) + (I_2 R_2) + (I_4 R_4) \\
 &= (150 \text{ mA})(5.0 \, \Omega) + (100 \text{ mA})(10 \, \Omega) + (150 \text{ mA})(4.0 \, \Omega) \\
 &= (0.150 \text{ A})(5.0 \, \Omega) + (0.100 \text{ A})(10 \, \Omega) + (0.150 \text{ A})(4.0 \, \Omega) \\
 &= (0.750 \text{ V}) + (1.00 \text{ V}) + (0.600 \text{ V}) \\
 &= 2.35 \text{ V} \\
 &= 2.4 \text{ V}
 \end{aligned}$$

Section 2: Follow-up Activities

Extra Help

1. a. Properties of Series Circuits



- e. The answer is shown on the previous diagram.

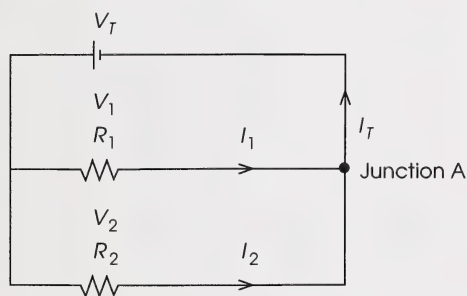
- b. The answer is shown on the previous diagram.

c. $V_T = V_1 + V_2$

$$\begin{aligned} \text{d. } \sum V &= 0 \\ V - V_1 - V_2 &= 0 \\ V_T &= V_1 + V_2 \end{aligned}$$

f. $I_T = I_1 = I_2$ g. $R_T = R_1 + R_2$

2. a. Properties of Parallel Circuits



- b. The answer is shown on the previous diagram.

c. $V_T = V_1 = V_2$

- d. The answer is shown on the previous diagram.

e. $I_T = I_1 + I_2$

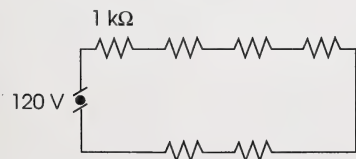
$$\begin{aligned} \text{f. } \sum I_{in} &= \sum I_{out} \text{ at Junction A} \\ I_1 + I_2 &= I_T \end{aligned}$$

g. $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$

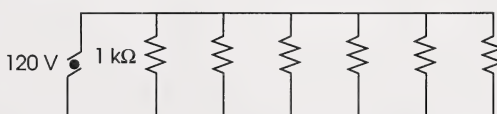
Enrichment

1. The answers will vary to this question because there are so many possible applications. However, most applications will involve measuring stresses and strains on materials in difficult to reach places or harsh environments. This might include the surfaces of aircraft, submarines, and possibly the interior regions of the heart (blood pressure).

2. a.



Parallel



b. Series

$$\begin{aligned}
 R_T &= \sum R \\
 &= 6(1.0 \text{ k}\Omega) \\
 &= 6.0 \text{ k}\Omega
 \end{aligned}$$

$$\begin{aligned}
 I_T &= \frac{V_T}{R_T} \\
 &= \frac{120 \text{ V}}{6.0 \times 10^3 \Omega} \\
 &= 0.020 \text{ A}
 \end{aligned}$$

$$\begin{aligned}
 \text{Cost} &= I_T V_T t \text{ cost/kW} \cdot \text{h} \\
 &= (0.020 \text{ A})(120 \text{ V})(8.0 \text{ h}) \left[\frac{1 \text{ kW}}{1000 \text{ W}} \right] (7.0\text{¢/kW} \cdot \text{h}) \\
 &= 0.13\text{¢}
 \end{aligned}$$

Parallel

$$\begin{aligned}
 \frac{I}{R_T} &= \sum \frac{1}{R} \\
 R &= 167 \Omega
 \end{aligned}$$

$$\begin{aligned}
 I_T &= \frac{V_T}{R_T} \\
 &= \frac{120 \text{ V}}{167 \Omega} \\
 &= 0.72 \text{ A}
 \end{aligned}$$

$$\begin{aligned}
 \text{Cost} &= I_T V_T t \text{ cost/kW} \cdot \text{h} \\
 &= (0.72 \text{ A})(120 \text{ V})(8.0 \text{ h}) \left[\frac{1 \text{ kW}}{1000 \text{ W}} \right] (7.0\text{¢/kW} \cdot \text{h}) \\
 &= 4.8\text{¢}
 \end{aligned}$$

c. The series setup is cheaper.

d. Power in series per bulb = $I^2 R$

$$\begin{aligned}
 &= (0.02)^2 (1.0 \times 10^3 \Omega) \\
 &= 0.40 \text{ W}
 \end{aligned}$$

Power in parallel per bulb = $I^2 R$

$$\begin{aligned}
 &= (0.12)^2 (1.0 \times 10^3 \Omega) \\
 &= 14.4 \text{ W} \\
 &= 14 \text{ W}
 \end{aligned}$$

The bulbs in parallel would be brighter, but more expensive.

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